

# Proposed Design Equations for the CFRP Strengthened Cold Formed Steel Built up I Sections

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**Abstract** This paper discuss the ultimate strength and design of cold formed built up steel sections by experimental and American (AISI-2007) standard method. For the experimental studies two cold formed steel channel members were connected back to back to form built up I sections and these channels are attached with screws. There were two sets of specimens were prepared such as plain and carbon fibre reinforced polymer (CFRP) strengthened built up columns. The prepared specimens tested for axial compression and results were noted. A series of parametric studies were also carried out by two different thickness and column length. The test results were compared with American (AISI-2007) Standards and proposed design equation using modular ratio concept method. The details of these investigation and the outcomes are presented in this paper.

**Keywords** Cold formed steel, Column, Built up, CFRP

## 1. Introduction

The use [1] of cold-formed steel structural members has increased in recent years, especially in light-weight steel construction, such as steel-framed housing, low-rise office buildings, factories, and warehouses. Cold-formed steel members are manufactured by either cold rolled or brake pressed into structural shapes. Cold-formed [2] steel light gauge members can be used efficiently in many structural applications. Similar to the heavy hot-rolled steel sections, cold-formed steel compression members can be used to carry a compressive load applied through the centroid of the cross section. Normally, [3, 4] three basic types of buckling, local, overall, and distortional, can occur in thin-walled steel sections. External fibre reinforcement will delay the buckling of the thin wall sections. More [5] recently, there has been a interest towards the use of externally applied composite fibre reinforcement in steel members which, combining the advantageous mechanical properties of different materials, leads to improved structural performance. FRP composites as a structural reinforcing material possess complementary material characteristics to concrete or steel, namely, higher strength-to weight ratio, ease of handling and high corrosion resistance, all of which

transcend other considerations.

The ultimate strength of plain and CFRP strengthened built up sections were tested experimentally in this study. The experimental results were compared with American (AISI 2007) standards. An equation is used to calculate the young's modulus of CFRP strengthened composite sections and the results were validate with experimentally tested results.

## 2. Test Set up and Experimental Procedure

**Table 1.** Sectional properties

No	Size	Thickness (mm)	$f_y$ (N/mm <sup>2</sup> )	Mass Kg/m	Area mm <sup>2</sup>
1	C75	0.6	550	0.78	97.8
2	C75	0.75	550	0.99	122
3	C75	1	550	1.3	137

**Table 2.** Sectional properties

No	Size	$I_{xx} \times 10^4$ mm <sup>4</sup>	$I_{yy} \times 10^4$ mm <sup>4</sup>	Section modulus $z_x$ (mm <sup>3</sup> ) $\times 10^3$	Section modulus $z_y$ (mm <sup>3</sup> ) $\times 10^3$
1	C75	9.02	1.91	2.39	0.72
2	C75	11.6	2.28	3.03	0.91
3	C75	12.2	2.85	3.25	1.02

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In this study cold formed lipped channel section were connected back to back with screws and strengthened with CFRP, a two phase experimental programme were conducted. In Phase 1, a total of 6 specimens of plain cold formed steel built up sections were tested. In Phase 2, a total of 6 specimens of CFRP strengthened cold formed sections were tested under concentric axial load. The sectional properties of single channel sections are as shown in Table 1 & 2. A pictorial view cfrp strengthened sections and the test setup is shown in Fig. 1 & 2. Two samples were used in each test and the average value was taken.



Figure 1. CFRP strengthened specimens



Figure 2. Experimental set up

### 3. Calculation Based on AISI (2007) Standard

Design method for CFRP strengthened channel section proposed to axial compression based on AISI standards

(AISI, 2007). To account CFRP, the Direct Strength Method (DSM) modified to estimate the ultimate strength of cold-formed steel columns experiencing flexural or flexural-torsional, local and distortional buckling. CFRP is assumed to play an important role in elastic buckling, slenderness ratio. The nominal axial strength  $P_n$  determined as minimum of ( $P_{ne}$ ,  $P_{nl}$  and  $P_{nd}$ ) based on DSM method is in Eq. 3, 4 and 5, proposed by Schafer (2006). Total thickness of CFRP layered plate ( $t_t$ ) considered as CFRP thickness ( $t_{cf}$ ) + steel plate ( $t_s$ ) neglecting adhesive layer thickness (as this is weak in strength and buckling) given by Eq. (1). The elastic modulus of the CFRP with steel is determined from the modular ratio concept and given by Eq. (2). This concept was checked before for CFRP strengthened channel section by Sreedhar kalavagunta (2013), same equations are used to validate the channel connected back to back as built up sections [7-9].

$$t_t = t_{cf} + t_s \quad (1)$$

$$E_{cfrp} = \frac{E_s t_s + E_{cf} t_{cf}}{t_s + t_{cf}} \quad (2)$$

Flexural, Torsional, or Torsional-Flexural Buckling ( $P_{ne}$ )

$$P_{ne} = \begin{cases} \left(0.658^{\lambda_c^2}\right) P_y & \lambda_c \leq 1.5 \\ \left(\frac{0.877}{\lambda_c^2}\right) & \lambda_c > 1.5 \end{cases} \quad (3)$$

where

$$\lambda_c = \sqrt{P_y / P_{cre}}$$

$P_{cre}$  = Minimum of the critical elastic column buckling load in flexural, torsional, or torsional-flexural buckling.

Local Buckling ( $P_{nl}$ ):

$$P_{nl} = \begin{cases} P_{ne} & \lambda_l \leq 0.766 \\ \left[1 - 0.15 \left(\frac{P_{crl}}{P_{ne}}\right)^{0.4}\right] \left(\frac{P_{crl}}{P_{ne}}\right)^{0.4} P_{ne} & \lambda_l > 0.766 \end{cases} \quad (4)$$

$$\lambda_l = \sqrt{P_{ne} / P_{crl}}$$

$P_{crl}$  = Critical elastic local column buckling load.

Distortional Buckling ( $P_{nd}$ )

$$P_{nd} = \begin{cases} P_y & \lambda_d \leq 0.561 \\ \left[1 - 0.25 \left(\frac{P_{crd}}{P_y}\right)^{0.6}\right] \left(\frac{P_{crd}}{P_y}\right)^{0.6} P_y & \lambda_d > 0.561 \end{cases} \quad (5)$$

where,

$$\lambda_{cd} = \sqrt{P_y / P_{crd}}$$

$P_{crd}$  = Critical elastic distortional column buckling load.

## 4. Results and Discussions

The experimental and design calculation results based on American standards (AISI 2007) of built columns are tabulated below.

**Table 3.** Plain built up cold formed steel ultimate load: Experimental Vs theoretical

Section	Ultimate Load-Experimental-kN	Ultimate Load-theoretical-AISI-kN
C7560 x 300	48.46	41.52
C7560 x 500	46.69	39.42
C7575 x 300	57.26	55.04
C7575 x 500	55.61	52.26
C7510 x 300	90.82	79.27
C7510 x 500	94.42	75.26

## 5. Conclusions

In this experimental study there were totally 12 built columns were tested. The ultimate strength of both plain and CFRP strengthened results were noted. As expected there is

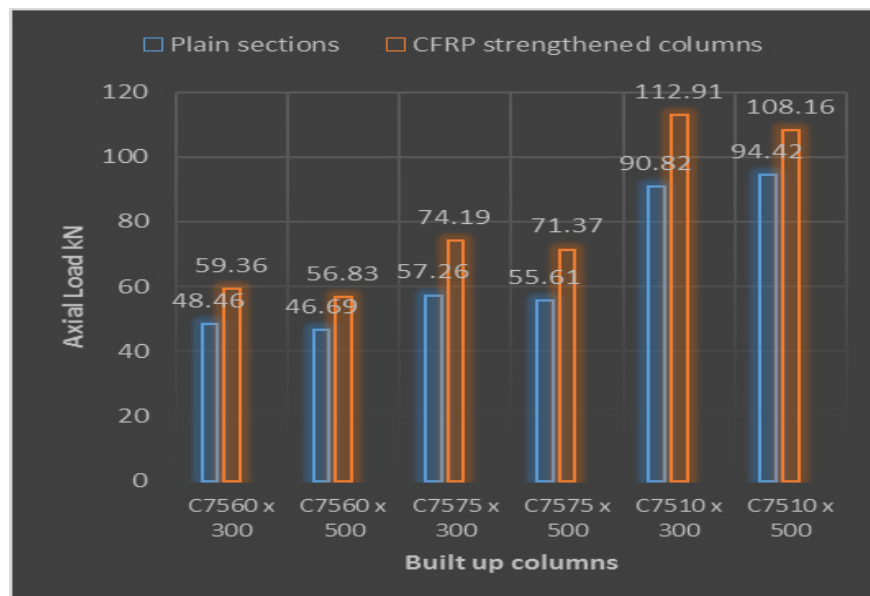
increase in strength of about 18.89% due to CFRP strengthening. The plain sections ultimate strength were calculated using direct strength method as specified in AISI standards and these results were closely matching with the experimental results. The proposed equations used for the calculations of CFRP strengthened built up columns using modular concept ratio method results also closely matching with the experimentally tested built up columns. There is chances of failure or pull out of screws will lead to reduction of ultimate strength of built up columns.

**Table 4.** CFRP strengthened cold formed steel-ultimate load: Experimental vs. theoretical

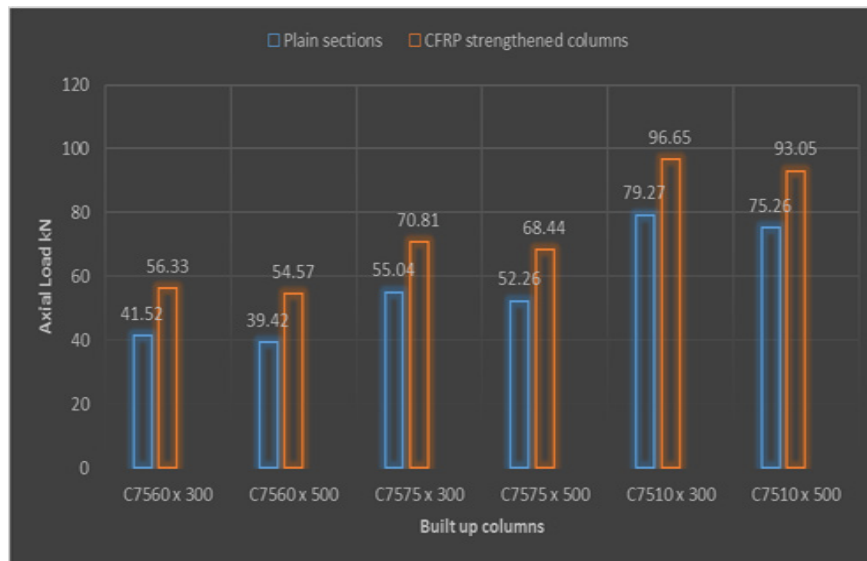
Section	Ultimate Load-Experimental-kN	Ultimate Load-theoretical-AISI-kN
C7560 x 300	59.36	56.33
C7560 x 500	56.83	54.57
C7575 x 300	74.19	70.81
C7575 x 500	71.37	68.44
C7510 x 300	112.91	96.65
C7510 x 500	108.16	93.05

**Table 5.** Increase of strength due to CFRP strengthening

Section	Ultimate Load-Experimental-kN (for plain section)	Ultimate Load-Experimental-kN (for cfrp strengthened section)	% increase in strength due to CFRP
C7560 x 300	48.46	59.36	18.36
C7560 x 500	46.69	56.83	17.84
C7575 x 300	57.26	74.19	22.81
C7575 x 500	55.61	71.37	22.07
C7510 x 300	90.82	112.91	19.56
C7510 x 500	94.42	108.16	12.70
Average percentage increase in strength			18.89%



**Figure 3.** Experimental results of plain and CFRP strengthened built up columns



**Figure 4.** Theoretical results of plain and CFRP strengthened built up columns as per AISI 2007

## REFERENCES

- [1] Ben Young, M.ASCE; and Ju Chen, Design of Cold-Formed Steel Built-Up Closed Sections with Intermediate Stiffeners. 10.1061/(ASCE)0733-9445(2008)134:5(727).
- [2] Yu, W. W. Cold-formed steel design, 3rd Ed, Wiley, New York.
- [3] Demao Yang and Gregory J. Hancock, Compression Tests of High Strength Steel Channel Columns with Interaction between Local and Distortional Buckling. 10.1061/(ASCE)0733-9445(2004)130:12(1954).
- [4] Sreedhar Kalavagunta, Sivakumar Naganathan and Kamal Nasharuddin Bin Mustapha, Experimental Study on CFRP Strengthened Cold Formed Channel Columns, Research Journal of Applied Sciences, Engineering and Technology 6(21): 4058-4062, 2013.
- [5] Jimmy Haedir, Xiao-Ling Zhao, Design of short CFRP-reinforced steel tubular columns, Journal of constructional Steel Research 67 (2011) 497–509.
- [6] Sreedhar Kalavagunta, Sivakumar Naganathan and Kamal Nasharuddin Bin Mustapha, Proposal for design rules of axially loaded CFRP strengthened cold formed lipped channel steel sections, Thin-Walled structures 72(2013) 14–19.
- [7] AISI (American Iron and Steel Institute), 2007. North American Specification for the Design of Cold-Formed steel structural members. Iron and Steel Institute, Washington, DC.
- [8] N. Silvestre, D. Camotim and B. Young on the use of the EC3 and AISI specifications to estimate the ultimate load of cfrp-strengthened cold-formed steel lipped channel columns, Asia-Pacific Conference on FRP in Structures (APFIS 2007).
- [9] Schafer, B.W., 2006, Designing cold-formed steel using the direct strength method. Proceeding of the 18<sup>th</sup> International specialty Conference on Cold-Formed Steel Structures. Orlando, Florida, October 26-27.
- [10] Nuno, S., C. Dinar and Y. Ben, 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 Wall. Struct., 47: 1102-1111.