Behaviour of wrapped cold-formed steel columns under different loading conditions

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Abstract. The use of Cold Formed Steel (CFS) sections as structural members is widely accepted because of its light nature. However, the load carrying capacity of these sections will be less compared to hot rolled sections. This study is meant to analyze the possibility of strengthening cold formed members by wrapping it with Glass Fiber Reinforced Polymer (GFRP) laminates. Light gauge steel columns of cross sectional dimensions 100mm x 50mm x 3.15mm were taken for this study. The effective length of the section is about 750mm. A total of 8 specimens including the control specimen is tested under axial and eccentric loading. The columns were tested keeping both ends hinged. For both loading cases the buckling behaviour, ultimate load carrying capacity and load-deflection characteristics of the CFS columns were analyzed. The GFRP laminates were wrapped on columns in three different ways such that wrapping the outer surface of web and flange throughout the length of specimen, wrapping the outer surface of web alone throughout the length of specimen and wrapping the outer surface of web and flange for the upper half length of the specimen where the buckling is expected. For both loading cases, the results indicated that the column with wrapping at the outer surface of web and flange throughout the length of specimen provides better strength for it.

Keywords: CFS column – channel section – GFRP laminates – axial loading – eccentric loading – wrapping – buckling.

1. Introduction

The application of thin-walled section at the global scenario in the field of engineering is having a massive spike due to its low self-weight, durability, non-combustibility and cost effectiveness in case of transportation and erection and also it provides greater flexibility which makes it suitable for longer spans. It is used as a structural element in the field of engineering. It is commonly available in C-section with and without lips, I-section, hat section and tubular section. Even though it has more merits, it has some demerits also. The main drawback is that the load carrying capacity is less as compared to hot rolled steel. These thin walled sections are liable to instability showing various modes of failure such as global buckling, distortional buckling and local buckling. The global buckling is further classified into flexural buckling, torsional buckling and flexural-torsional buckling. The primary factors which influence the buckling behaviour is the slenderness ratio. The other factors that will affect the behaviour of CFS sections are the imperfections in the material, damages that occur for the section during transportation and installation, connections between the members and eccentricity of loading. These possibilities of failure of elements raises demand for strengthening techniques to meet serviceability for the designed life span. The performance of CFS members majorly depends on its
material and sectional properties. As of now many studies have been done in strengthening the existing members. Some of the common methods of strengthening are by providing bracing, steel jacketing and wrapping it with fibre laminates. In this study, an attempt was made to strengthen the CFS column specimen by wrapping it with Glass Fiber Reinforced Polymer (GFRP) laminates. Previous studies carried out by Sreedhar Kalavagunta et al. provides details of optimum strengthening of columns with Carbon Fiber Reinforced Polymer [1] and P. Manikandan et al. explains the behaviour of stiffened CFS channel section [2]. Bamback et al. proposed that strengthening of column with CFRP subjected to axial loading increases the strength up to 2 times of that of control specimen [3]. Thomas H.K.Kang et al. described the different types of buckling modes for CFS column with different cross sections [4]. Hélder D. Craveiro et al. provided details about the difference in the buckling behaviour of single and built-up cross section with different end conditions [5]. Sreedhar Kalavagunta et al. gives details of the adhesive which can be used for attaching the laminate with the column section and gives a clear idea of the setting time for better binding [6]. M.A. El Aghoury et al. carried out a study on battened column subjected to eccentric loading which shows method of provision of eccentricity for loading in detail [7].

In this study channel section without lips is used and GFRP is used as the strengthening material. The strength mainly depends on the bond between fiber and the member hence proper bond is provided with epoxy resin. The main objective of this study is to determine the ultimate load carrying capacity and to differentiate the buckling behaviour of CFS members with and without wrapping.

2. Materials
2.1. Cold Formed Steel
The light gauge steel sections are cold formed. That is, these are made by rolling it in cold condition or by bending it in press brakes. These are used in the structure where the elements are subjected to light or moderate loads which make the structure economical.

2.2. GFRP Laminate
Fiber glass is a strong light weight material and it is mainly available in various forms such as bars, sheets, laminates. The GFRP laminates are typically processed in a hand lay technique, where the sheet of fibers are placed and brushed with a resin at room temperature.

3. Experimental Setup
3.1. Test Specimens
In this study total of 8 numbers of CFS channel section of 100mm x 50mm x 3.15mm cross sectional dimension as shown in Figure 1 with an effective length of 750mm is tested as columns. Specimens are grouped in to two based on the loading conditions. Each group is having 4 specimens in which one is the control specimen. The other three specimens are wrapped in 3 different patterns such as wrapping the outer surface of web and flange throughout the length of specimen, wrapping the outer surface of web alone throughout the length of specimen and wrapping the outer surface of web and flange for the upper half length of the specimen where the buckling is expected. The load is applied axially and eccentrically with both ends hinged condition. The hinged condition is provided with a setup of two plates with a ball at the center. The sectional details of CFS channel section are given in Table 1 [8].

| Dimensions l x b x t mm | A mm² | C_y Mm | I_xx mm⁴ | I_yy mm⁴ | R_xx mm | R_yy mm | Z_xx mm³ | Z_yy mm³ |
|-------------------------|-------|--------|----------|----------|--------|--------|--------|--------|
| 100 x 50 x 3.15         | 587   | 14.2   | 90 x 10⁴ | 14.6 x 10⁴ | 39.2   | 15.8   | 18 x 10⁷ | 4.06 x 10⁷ |
The GFRP laminates of thickness 1mm and length which is required for wrapping is taken. Since the load applied is compressive, a uni-directional GFRP laminate is chosen. That is all the fibers are arranged in a single direction. The bond between the GFRP laminate and the column section is made using epoxy based adhesive and let it to set in a week of time at room temperature. The specimen details are given in Table 2.

| Notations | Specimen Details                                      | Notations | Specimen Details                        |
|-----------|------------------------------------------------------|-----------|----------------------------------------|
| AC        | Axially loaded Control Specimen                      | EC        | Eccentrically loaded Control Specimen  |
| AWS       | Axially loaded Web Strengthened specimen             | EWS       | Eccentrically loaded Web Strengthened specimen |
| AWFS      | Axially loaded Web and Flange strengthened specimen. | EWFS      | Eccentrically loaded Web and Flange strengthened specimen. |
| AES       | Axially loaded partially (upper half length) wrapped specimen. | EES       | Eccentrically loaded partially (upper half length) wrapped specimen. |

A coupon test was conducted to determine the material properties of GFRP laminates. GFRP laminates did not show any yielding and the failure was observed at the ultimate load. The material properties of CFS and GFRP are listed in Table 3.

![Figure 1. Cross sectional view of specimen](image)

**Table 3. Material properties**

| Material | Young’s modulus, \( E \) N/mm\(^2\) | Poisson’s ratio, \( n \) | Yield stress, \( S_y \) N/mm\(^2\) | Ultimate Tensile Strength N/mm\(^2\) |
|----------|--------------------------------------|--------------------------|-------------------------------------|-------------------------------------|
| CFS      | \( 2 \times 10^3 \)                  | 0.3                      | 545                                 | 632                                 |
| GFRP     | \( 0.26 \times 10^3 \)               | 0.28                     | 530                                 | 530                                 |

3.2. Test Setup and Experimental Program

In axial loading case, the test specimens were placed in a loading frame of capacity 1000kN in such a way that the line of action of load coincides with the axis of the specimen. In eccentrically loaded columns the line of action of load coincided with the eccentric axis. The maximum eccentricity of
0.05d was considered where d is the higher lateral dimension. One LVDT is used to measure the mid-height deflection in web and another is used to measure the lateral deformation of flange. The load and deflection values were acquired using the digital data acquisition system. The scheme and the test setup is shown in Figure 2.

![Figure 2a. Schematic diagram of the experimental setup](image)

![Figure 2b. Test setup](image)

4. Results and Discussion
The buckling behavior, ultimate load carrying capacity and load-deflection characteristics of the wrapped and unwrapped CFS columns under axial and eccentric loading were analyzed. The ultimate load carrying capacity of the wrapped specimen is compared with that of control specimen for both the loading conditions. The ultimate load carrying capacity of specimens obtained experimentally and theoretically for axial and eccentric loading conditions is listed in Table 4.

| Specimens | Experimental kN | Specimens | Experimental kN |
|-----------|-----------------|-----------|----------------|
| AC        | 82.5            | EC        | 53.11          |
| AWS       | 129.1           | EWS       | 66.5           |
| AWFS      | 148.6           | EWFS      | 89.9           |
| AES       | 117.1           | EES       | 81.9           |
The comparisons between the ultimate load carrying capacity of axially and eccentrically loaded specimen are shown in Figure 5 and Figure 6 respectively. The buckling behaviour of the CFS sections were observed. It is noted that the control specimens showed distortional buckling as shown in Figure 4 and Figure 5 and the specimens which are wrapped at the web alone also shows the same behaviour but the specimens with wrapped web and flange and the specimen with partially wrapped web and flange showed local buckling as shown in Figure 4 and Figure 5.

It was observed that in both loading cases, the column with fully wrapped web and flange shows better results. The Load-Deflection behaviour of the axially and eccentrically loaded specimens is shown in Figure 7 and Figure 8 respectively. Figure 7 and Figure 8 represents that the control specimen deflects more in both cases and the wrapped specimens deflects less as compared to control specimen.
Figure 5. Ultimate load of axially loaded specimens

Figure 6. Ultimate load of eccentrically loaded specimens

Figure 7. Load vs Deflection - axially loaded specimens
5. Conclusion

- There was 79.3% and 67.7% increase in load carrying capacity of column with fully wrapped web and flange under axial and eccentric loading respectively.
- For columns wrapped at web portion alone, the load carrying capacity was increased by 57.5% and 25.2% under axial and eccentric loading respectively.
- 47.5% and 54.2% increase in load carrying capacity was observed for columns wrapped partially at the top portion of web and flange under axial and eccentric loading respectively.
- The columns which are wrapped at flange and web throughout the length of the column provides better strength than others specimens. This is due to the strengthening of column as a result of the confinement.

References

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