Square metallic tubular sections bonded with high strength carbon fibre sheets under compression

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Abstract: This paper presents the strength and stiffness enhancement of square steel hollow sections wrapped by Carbon Fibre Reinforced Polymer (CFRP) strips. Main factors used were number of layers and size of the CFRP. Distances between the adjacent strips are kept constant spacing of 40 mm. According to the objective of the study, twelve hollow steel sections are wrapped by carbon fibre strips and two samples are without wrapping is kept reference for comparison. Results confirmed that the strength and stiffness are improved better for carbon fibre wrapped samples compared to unwrapped sample.

Keywords: Hollow steel section, FRP sheet, Compression, Stiffness, Number of layers and width of CFRP

1. Introduction
Metallic building constructions are increased widespread in recent times owing to improved advantages like strength and ductility. They are available in different forms in structural applications and hollow steel tubular members are frequently used as beams and columns now a day. Few reasons such as severe environmental exposure, heavy impact loads and fatigue loads causes buckling failure in hollow steel tubular members [1]. Construction industry needs a permanent solution without any further maintenance until their service life. Another important parameter considered before choose the repair/strengthening material is the self-weight. Fibre Reinforced Polymer (FRP) composites satisfy the above needs with easy application in the field with limited labour and time period. There have been sufficient researches conducted on concrete column with FRP strengthening [2, 3, 4, 5 and 6]. Sectional stiffness and deflection [7], cracking behaviour [8] and flexural behaviour [9 and 10] and ultimate strength of RC retrofitted beams [11] were discussed by many researchers. Study related to metallic structural strengthening and repair by FRP composites are explained in detail. For example, corroded circular steel columns retrofitted by AFRP sheets and the ultimate strength and stiffness improvement were discussed [12]. Fatigue strength of butt weld square steel sections are improved by CFRP sheets [13]. Elephant foot’s buckling of metallic cylindrical shell was improved by FRP [14, 15 and 16]. Concrete- filled stainless- steel tubes wrapped by CFRP sheets to enhance flexural behaviour and a model was developed to correlate the test results [17]. Centre cracked steel plates are restored by CFRP material and the fatigue strength were investigated [18]. Ultimate load enhancement of about 97% and 169% was achieved by repair and reinforcement of steel pipeline [19]. Strength improvement...
of around 79% was achieved in steel concrete composite girder using CFRP sheets. A model was suggested to predict the results [20].

2. Investigational Segments

2.1 Ingredients

2.1.1. Metallic sections

Metallic Hollow sections are selected based on IS IS 1161-1998 of size (91.5× 91.5) mm square shape and 3.6 mm thickness.

2.1.2 Carbon filament sheet

Carbon fibre sheet (MBRACE 240) issued by BASF were considered for wrapping the metallic section having a thickness of 0.234 mm. Tensile and yield value of fibre sheet is 3800 Mpa and 240000 Mpa respectively.

2.1.3 Bonding matrix

Resin (Epoxy) and hardener ratio of 100: 40 were considered as bonding agent (Mbrace saturant).

2.2 Specimen

Specimens were shortening into required size of 600 mm height. Totally four samples were used in the present research and their specimen ID’s and the wrapping pattern are presented in the Table 1. Sand blasting technique was performed to attain perfect bonding. Carbon sheets are cut into required size and glued on steel section with the help of resin mix based on wrapping pattern.

| Sl.no | Specimen title     | Width of sheet | Spacing | Number of layers |
|-------|--------------------|----------------|---------|-----------------|
| 1     | Control (CC)        | ---            | ---     | 0               |
| 2     | 70 mm (1 layer)     | 70 mm          | 50 mm   | 1               |
| 3     | 70 mm (2 layers)    | 70 mm          | 50 mm   | 2               |
| 4     | 70 mm (3 layers)    | 70 mm          | 50 mm   | 3               |

3. Equipment arrangement

Pictorial representation of equipment arrangement was presented in Figure 1. Compression test was performed under 150 tonnes capacity column testing machine [21-2]. Load cell kept in position over the specimen and hydraulic jack is used for apply uniform loading. Three LVDT’s are kept at different places to measure the deformation and is connected to the sixteen channel data logger. Samples were loaded till their failure.

4. Summaries of Results

4.1 Specimens Failure criteria

Failure mode for specimen zero wrapping is local buckling happened at the bottom which is shown in the figure 1. As in the case of 70 mm width and 50 mm space wrapped samples the failure is purely fibre rupture due to outward buckling and the pictorial representation is given in figure 2. Number of layers plays major role in the peak load improvement compared to zero layers by providing
additional confinement. Comparing all wrapping, 3 layers wrapped sample shows high ultimate load compared to 1 and 2 layer. Also it was noticed that, from the three cases 70 mm with three layers displayed high load compared to 1 and 2 layers.

Figure 1. Failure criteria – Zero layer

Figure 2. Failure criteria- Wrapped member

4.2 Number of Sheets on Stress-Strain Characteristics

Figure 3 denoted the influence of number of layers on stress-strain characteristics for thirty mm width and fifty mm width CFRP sheets. The curve displayed similar pattern for single, double and three layers. But the increase in trend after the linear portion of zero layers is high due to the activation of fibre sheets. From the curve, the 70 mm wrapped with 3 layers displayed high nonlinear characteristics with low strain compared to 70 mm width having one and two layers. The peak load of all samples and the corresponding deflections were listed in the Table 2.

Figure 3. Seventy millimetre strips (Stress-strain)
### Table 2. Peak load and deformation details

| Sl.No | Title ID   | Highest load (kilo Newton) | Percentage increase (%) | Deformation (millimeter) |
|-------|------------|----------------------------|-------------------------|--------------------------|
| 1     | CC1        | 560.00                     | ---                     | 8.94                     |
| 2     | CC2        | 565.00                     | ---                     | 8.89                     |
| 3     | HS-70-50-T1(1) | 717.00                  | 26.90                  | 8.08                     |
| 4     | HS-70-50-T1(2) | 719.00                  | 27.26                  | 8.01                     |
| 5     | HS-70-50-T2(1) | 745.00                  | 31.86                  | 7.79                     |
| 6     | HS-70-50-T2(2) | 747.00                  | 32.21                  | 7.72                     |
| 7     | HS-70-50-T3(1) | 769.00                  | 36.11                  | 7.67                     |
| 8     | HS-70-50-T3(2) | 771.00                  | 36.46                  | 7.65                     |

#### 4.3 Influence of number of layers in Strength improvement

Pictorial representation of strength improvement at peak load with respect to layers wrapped is presented in figure 4. According to this picture, for single layer, the average compressive strength are 26.90 %, for double layer the average compressive strength was 32.21 % and three layer the average compressive strength was 36.46 % high than the zero layer wrapped member. Among the two schemes, the three layer wrapped sample provided high compression value than the single and double layer wrapped. Also it was observed that the seventy millimetres width and three layers prove to be the better among the schemes.

![Figure 4. Peak load Vs layers wrapped](image_url)
4.4 Influence of number of layers on Stiffness

Figure 7 shows the stiffness with respect to different layers and constant breadth. The increase in stiffness was significant compared to zero layers for 70 mm breadth CFRP strips. Average stiffness for specimens 70 mm (1 layer), 70 mm (2 layers) and 70 mm (3 layers) were 89.76kN/mm, 96.76kN/mm and 100.78kN/mm, respectively. Also the percentage increase of single layer, double layer and triple layers compared to zero layers were 41.24%, 52.25% and 58.58% respectively. The increase was steady up to the peak load due to fibre activeness and thereafter a sudden drop occurs when the fibre starts rupture.

![Figure 5. Stiffness with respect to number of sheets](image)

5. Conclusions

Based on compression test performed on samples, the following conclusions are drawn. Number layers not changing the failure mode, but they increase the peak load by delay the buckling and deformation. Compression load percentage at peak for single layer (70mm breadth and 50 mm space) is 27.26% for two layers (70 mm breadth and 50 mm space) is 32.21%, for three layers (70 mm breadth and 50 mm space) is 36.46% respectively more than control. Seventy millimeters (70mm) wrapped with 3 layers displayed high nonlinear characteristics with low strain compared to one and two layers. The average stiffness for specimens 70 millimetre (1 layer), 70 millimetre (2 layer), 70 millimetre (3 layer), were 89.76kN/mm, 96.76kN/mm and 100.78kN/mm respectively. Overall the members wrapped by three layers showed higher strength and stiffness improvement.

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