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Axial Behaviour of Square HSS Tubular Members Strengthening with CFRP Sheets

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Abstract*: Hollow structural steel (HSS) tubular sections are increasingly popular now in many metallic structures for economic and effective standpoint, but they suffer severe fatigue crack and deterioration due to the severe environmental condition. Fibre reinforced polymers (FRP) can solve the above mentioned complications effectively. FRP composite materials on steel tubular structures are having very good attachment and exhibit similar property. Due to this merits, FRP-Steel combination increased in the construction industry in recent era. Current research work demonstrated the different forms of orientation and combination (transverse and longitudinal) of CFRP wrapping on HSS tubes under axial compression. In this experimental program, unidirectional CFRP sheets are used as a continuous sheets bonded to HSS specimens both transverse and longitudinal direction. Totally eighteen HSS tubes were used for axial compression testing. Among eighteen columns, sixteen columns were externally bonded by CFRP strips and the remaining two columns were unwrapped (Control). After the compression test, various aspects like effect of inclusion of transverse and longitudinal CFRP fabrics, load carrying capacity and stress strain characteristics were investigated. Experimental results also revealed that, addition of more transverse CFRP fabrics significantly increases the ultimate load and stress-strain capacity compared to that of longitudinal CFRP inclusion.

***Index Terms*: Hollow structural steel, Orientation, Compressive strength, wrapping, local buckling**

I. INTRODUCTION

Hollow structural steel (HSS) tubes uses in buildings, bridges, towers and marine structures were increased in recent decades due to their superior mechanical and strength characteristics. But they get deteriorated and failed due to various reasons like severe environmental condition, impact loading, fatigue loading, design faults and construction faults. Advanced construction materials like Fibre Reinforced Polimer (FRP) composites are overcome the above mentioned shortcomings. FRP composites have lot of advantages over traditional techniques like, less weight, high strength, high corrosion resistance, easy bonding with minimum labours and minimum service interruption during repair works. Also FRP composites are made into any shape and do not require frequent repair. Lot of past researches had shown the successful application of FRP on RC structural members. FRP composites are used as different kinds of confinement in structural elements and contribute to the improvements in structural behavior [1].

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Column members externally confined by FRP composite materials subjected different loadings displayed substantial increase in strength and stiffness [2]. RC columns damaged due to earthquake can be wrapped with FRP sheets significantly increases strength and ductility [3]. Strength and ductility properties of cylindrical reinforced concrete columns were increased because of CFRP wrapping under axial compression [4]. Shear and flexural measurements of reinforced concrete beam members were improved because of CFRP sheet wrapping. GFRP strips considerably reduce the crack widths at all the levels of loading [5]. CFRP sheets wrapped on beams with different orientation have increase the strength and ductility [6]. Several reinforced beams damaged due to various loading and environmental condition were repaired by CFRP sheets [7 and 8]. After successful use of FRP on RC members researchers started using FRP for steel structural strengthening in the past few decades [9]. [10] Conducted a research on beam member strengthened with CFRP. Both strengthened and unconfined sections, showed a 5% loss of stiffness when subjected to the fatigue cycles. However, whilst the strengthened beams had only a 10% increase in deflections, the unconfined beam had a 30% increases in deflection. [11] Introduced some new strengthening procedure on steel beams using CFRP to reduce the web buckling failure. [12] Performed the study on steel slender columns confined with CFRP. Specimens were strengthened by various layers and tested at compression testing machine. A result obtained from the experimental study says that the column wrapped by CFRP delays the buckling and increases the strength and ductility. Finally, analytical studies were conducted and compared with the experimental results. [13] Investigated strength increment of hollow steel tubes externally strengthened by GFRP sheets. The key factor used was, adding the GFRP sheets. Main failure occurs in the bare column during compression test was an elephant foot's buckling. GFRP wrapping significantly reduce the elephant foot's buckling but increase the ductility. [14] Studied the usefulness of hybrid CFRP sheets on artificially failed steel beams. Two types of wrapping schemes were performed. One is GFRP U wrapping performed up to the neutral axis and the remaining one is CFRP bonded soffit only. Results revealed that the hybrid CFRP exhibits ductile response and no fibre breakage.

The above literatures demonstrated the effectiveness of CFRP on RC and steel structural members. But fewer studies were available related to HSS tubes wrapped with CFRP sheets. More studies were required to identify the most suitable and optimized wrapping scheme because now they are used in all type structural elements. The current study focuses on the effectiveness of CFRP on HSS tubes and also studied the

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impact of adding number of layers, alternate wrapping (Transverse and horizontal layers) and the combination of these two.

II. MATERIALS

A. CFRP Composites

Table 1. CFRP Sheet Details

Manufacturer	BASF India Inc
Type of CFRP	Unidirectional carbon fibre (MBrace 240)
Elasticity	240 kN/mm^2
Flexible Strength	3800 N/mm^2
Weight	230 g/m^2
Density	1.7 g/cm^2
Sheet thickness	0.234 mm

B. Resin Matrix

Resin and hardeners used in this current study was purchased from BASF India Inc. Mix ratio prescribed by the manufacturer was 100:40.

C. HSS Members

The HSS members were purchased based on IS 4923 -1997. The dimensions of HSS members are presented in Table 2.

Table 2. Dimensions of HSS member

Sl.No	Dimension (mm)	Thickness (mm)	Length (mm)	Yield strength (N/mm^2)
1	91.5× 91.5	3.6	600	480

III. EXPERIMENTAL PROGRAMME

A. Specimen Label

Total numbers of specimens used in this study were twenty. Among twenty specimens, two were unwrapped and the remaining eighteen specimens were wrapped by CFRP sheets with different combinations. To identify the specimens easily they are named as CC1, FW-T1, FW-T2, FW-T3, FW-T1L1, FW-L1T1, FW-(1T+1L+1T), FW-(1L+1T+1L), FW-(2T+1L) and FW-(2L+1T). For example, FW-T1, FW-T2, and FW-T3 represent the specimens wrapped by single, double and three transverse orientations. Similarly specimens FW-T1L1 and FW-L1T1 indicated the full wrapping with two layers. In the case of FW-T1L1, first layer is in transverse followed by the second layer in horizontal direction. Similarly for FW-L1T1, first layer was wrapped by longitudinal followed by the second layer in transverse direction. Control column was specified as CC1.

B. Specimen Fabrication

The heights of the columns were 600 mm and are cut from the 6 m long hollow tubes. Surface preparation is important criteria for perfect bonding of CFRP sheets on steel tube. In order to make the surface rough, all columns are undergone sand blasting and are presented in figure 1. Before starting the wrapping procedure, impurities presented on the column surfaces were removed by acetone. Steel specimens are prone to corrosion (Galvanic Corrosion) when they get direct contact with CFRP sheets. To avoid the direct contact, GFRP sheets are wrapped in the form of surface mat. Finally, CFRP sheets were wrapped based on the required orientation. Resins with hardeners are mixed as per the mix proportion given by the manufacturer. Excess resin and the air gaps between CFRP sheets could be removed by steel rollers. HSS columns wrapped by continuous CFRP sheets were presented in figure 2.

Fig.1. Columns after Sand Blasting

Fig.2. Specimen Wrapped with CFRP

C. Instrument Details

Curing completed specimens went for compression testing with the help of 2000 kN capacity column tester. Loads are given to the testing specimen by hydraulic jack through 1000 kN load cell. LVDTs are placed in proper position for monitoring the deflection. Load cell and LVDTs are coupled with a 16-Channel Data Acquisition System, which monitor both load and deflection readings. Figure 3 shows the full arrangements of experimental setup.

Fig. 3. Instrument setup

IV. EXPERIMENTAL RESULTS

Compression failure, ultimate loads and corresponding deflection were found out from the compression testing and are discussed briefly by comparing one another and with control specimen.

A. Compression Failure

Compression failure of specimens wrapped by CFRP and unwrapped specimens were presented in figure 4 to 9. Specimen CC-1, local buckling takes place at the bottom similar to elephant's foot buckling [13]. Figure 4 represented the failure mode of control column CC-1. Figure 5 to 7 represented the compression failure of FW-[T1], FW-[T2] and FW-[T3]. All three specimens mentioned above are failed at the top followed by fibre rupture occurred with a huge sound. No delamination was taken place till the fibre rupture. This result shows the confinement effectiveness provided by CFRP sheets with HSS members. As expected, the compressive load improved with an inclusion of more CFRP layers. Failure modes for columns FW-L1T1 and FW-T1L1 were presented in figure 8 and 9. Here we observed that the failure and fibre rupture take place at the top. No fibre delamination till the fibre rupture. This result confirms the proper bonding of CFRP on steel tubes. Fig.10-13 shows the failure mode of columns (FW-[1L+1T+1L] and FW-[1T+1L+1T]) confined with three CFRP layers arranged in different orientation. From the figures it was observed that, for both columns the failure take place at the bottom similar to CC-1, but the load increment was quiet higher compared to control column. Figure 14 and 15 shows the failure mode of specimens FW-[2L+1T] and FW-[2T+1L]. For both columns FW-[2L+1T] and FW-[2T+1L], failure take place at top similar to the first two wrapping scheme. Fibre rupture occurred with huge noise at the failure place. From the above observation it was noted that the transverse layers resist the local buckling effectively compared to specimens wrapped with longitudinal layers.

Fig. 4. Compression failure CC-1

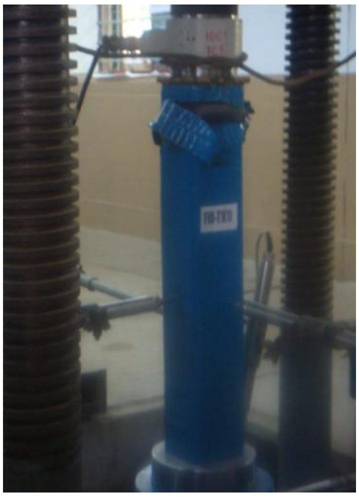

Fig. 5. Compression failure FW [T1]

Fig. 6. Compression failure FW-[T2]

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Fig. 7. Compression failure FW-[T3]

Fig. 8. Compression failure FW-[L1T1]

Fig. 9. Compression failure FW-[T1L1]

Fig. 10. Compression failure FW-[1T+1L+1T]

Fig. 11. Compression failure FW-[1L+1T+1L]

Fig. 12. Compression failure FW-[2L+1T]

Fig.13. Compression failure FW-[2T+1L]

B. Stress-Strain relation

Figure 14 compares the stress-strain relations of all confined columns with control column. Control column behaved elastically at the beginning stage and continued up to the peak load thereafter the curve falls down suddenly. The reason is that the column underwent local elastic buckling after reaches the ultimate load and column does not transfer the axial stress to the section. All confined columns exhibited ascending curve till reach the ultimate load, thereafter the curve falls down suddenly because of fibre deactivation. Deformation control for columns confined with CFRP and unconfined control columns were presented in Table 1. Specimens wrapped with more number of transverse layers showed better axial control that of specimen with CFRP in longitudinal orientation. Because, transverse layers bonded perpendicular to the direction of load.

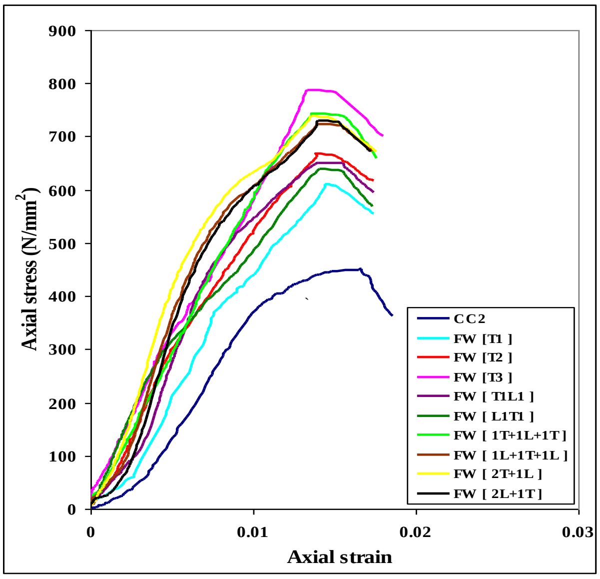

Fig.14. Stress- Strain relation curve

C. Compression Strength

Compression strength and the corresponding percentage increment compared to CC2 were summarized in Table 3. Figure 15 relates the compressive strength increment of specimens wrapped by CFRP and control column. Compression strength of specimens confined by transverse layers FW-T1, FW-T2 and FW-T3 showed 36.637%, 49.380% and 76.460% respectively compared to control column CC2. For columns FW-T1L1 and FW-L1T1, the increment was noted that 45.486% and 43.0% more to that of CC2.

Table 3. Compression Strength and Deflection

Sl. No	Specimen label	Compression strength (kN)	% increment compared to CC2	Deflection in mm
1	CC1	560.00	-	-
2	CC2	565.00	-	-
3	FW-T1(1)	772.00	36.637	8.67
4	FW-T1(2)	769.00	36.106	8.72
5	FW-T2(1)	840.00	48.672	8.29
6	FW-T2(2)	844.00	49.380	8.25
7	FW-T3(1)	989.00	75.044	7.96
8	FW-T3(2)	997.00	76.460	7.99
9	FW-L1T1(1)	802.00	41.946	8.50
10	FW-L1T1(2)	808.00	43.000	8.45
11	FW-T1L1(1)	822.00	45.486	8.41
12	FW-T11L1(2)	817.00	44.601	8.44
13	FW-[1L+1T+1L]-(1)	916.00	62.123	8.21
14	FW-[1L+1T+1L]-(2)	909.00	60.884	8.23
15	FW-[1T+1L+1T] - (1)	938.00	66.017	8.21
16	FW-[1T+1L+1T] - (2)	934.00	65.309	8.18
17	FW-[2T+1L]-(1)	928.00	64.247	8.18
18	FW-[2T+1L]-(2)	941.00	66.548	8.15
19	FW-[2L+1T]-(1)	923.00	63.362	8.23
20	FW-[2L+1T]-(2)	921.00	63.008	8.22

Percentage increment of compression strength for columns wrapped with three CFRP layers in different orientation FW-[1L+1T+1L], FW-[1T+1L+1T], FW-[2T +1L] and FW-[2L+1T] were found to be 62.123%, 65.309%,66.548% and 63.362% respectively more compared to CC2.

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Results confirmed that, specimen first layer confined by transverse direction with additional two CFRP layers showed more compression strength compared to specimen laid with more longitudinal layers. Because transverse layers are perpendicular to the load direction. The transverse layers were effectively defying the elastic buckling that of longitudinal fibre layers; also CFRP is a uni-directional fabric. From the above observation, column confined with more number of transverse layers showed more compressive strength compared to specimen confined with longitudinal layers.

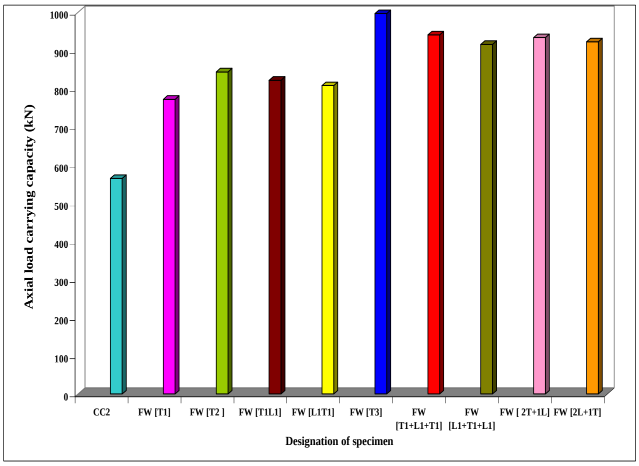

Fig.15. Compression strength -Comparison

V. CONCLUSIONS

Axial compression test was performed on twenty HSS columns and the following conclusions were conquered:

- Compression strength increment of specimens FW-T2, FW-L1T1 and FW-T1L1compared to CC2 was 49.380%, 43.000 and 45.486 respectively.
- Percentage increase in compressive strength for columns FW-[T3], FW-[1T+1L+1T], FW-[1L+1T+1L], FW-[2T+1L], and FW-[2L + 1T] compared to CC2 was 76%, 65.31%, 62.12%, 66.55% and 63.36% respectively.
- Compression strength results showed that the specimen first layer wrapped with transverse direction and more number of transverse layers showed much better compression strength compared to specimen first layer laid by longitudinal layers and more number of longitudinal layers.
- Deflection control also higher in the case of transverse layers compared to longitudinal layers.
- Transverse layers resists the buckling more effectively compared to longitudinal layers, since they are at right angles to the direction of loading.

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