

EXPERIMENTAL INVESTIGATION ON HCS SECTION STRENGTHENED BY CARBON AND GLASS LAMINATES

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Abstract - This paper presents the experimental and investigations on the structural behaviors of Hollow Circular Section Steel (HCS) compression members were strengthened using Fiber Reinforced Polymer (FRP) laminates. The hollow circular steel section is used throughout the world. More excellent properties of the tubular shape with regard to loading in tension, compression and bending in all directions. However, the behaviour of these sections is characterized by a range of buckling modes and displacement of the steel columns. To increase the strength and durability of steel structure, Carbon- glass laminates (CFRP and GFRP) are to be used as a cold formed steel section. The different fibres combinations are used for in this paper (one layer of GFRP laminate placed between two layers of CFRP laminates). In this paper the two types of CFRP wrapped with the cold formed steel section, which gives high strength and resists the buckling behavior. FRP has been established as an effective method of strengthening of steel and concrete. New technique of using FRP combination of fiber laminates has gained importance as the bond that has been created by wrapping. Use carbon fiber and glass fibre laminates in the section to increase the load bearing capacity also delay the buckling failures. The stability, load bearing capacity and failure modes for the two different steel wrapped sections are found by experimental test for under axial loading.

Keywords: Steel Hollow circular Sections, Carbon fibre Reinforced Polymer, Glass fibre Reinforced Polymer, FRP, axial loading, steel columns, Strengthening, Compression members.

1. INTRODUCTION

A hollow structural section (HSS) is a type of metal profile with a hollow tubular cross section. The term is used predominantly in the United States, or other countries which follow US construction or engineering terminology. HSS members can be circular, square, or rectangular sections, although other shapes such as elliptical are also available. Rectangular and square HSS are also commonly called tube steel or structural tubing. Circular HSS are sometimes mistakenly called steel pipe, although true steel pipe is actually dimensioned and classed differently from HSS. CFS sections are using for in this project Cold-Form Steel buildings are a

predetermined assembly of structural members that has proven over time to meet a wide range of structural and aesthetic requirements. Cold-Formed Steel (CFS) is the common term for products made by rolling or pressing steel into semi-finished or finished goods at relatively low temperatures. CFS goods are created by the working of steel billet, bar, or sheet using stamping, rolling or presses to deform it into a usable product. Steel concentrated structures are popular almost all over the world. Hollow Circular Steel (HCS) tubes are progressively more used both in building and bridge structures due to their well-organized geometry. During their service life, these members are subjected to loading of various types such as axial loading, bending and torsion. Rehabilitation of such structures is frequently required owing to loss of cross-section from corrosion and changes of the demand or use of a structure's are rolled from steel sheet or slit coil.

Fibre-Reinforced Polymer (FRP) is a composite material made of a polymer matrix reinforced with fibres. The polymer is usually an epoxy, vinyl ester, are still in use. Fibre-Reinforced Polymer (CFRP) composite materials have been increasingly employed in the construction industry, mainly in applications dealing with structural strengthening and repair. The rehabilitation of steel structures is usually in the form of strengthening of structural members or retrofitting the seismic deficiencies. Carbon fibre reinforced plastics have proven to be an excellent option as an external reinforcement because of their high tensile strength, resistance to corrosion, high durability, and ease of installation. The applicability and cost-efficiency of the CFRP strengthening concept depends largely on the material behavior of the member to be strengthened. Until now, the research activity in this area has been mainly focused on bond characteristics, local-plate and/or distortional buckling behaviors, design method, fatigue behaviour of tensile steel/CFRP joints.

Ashvini and Swaminathan experimentally analysed The CFRP confinement of circular hollow steel tubes leads to great increase in ductility with limited increases in strength. There are two different matrix layouts of carbon fibres on the axial capacity and crushing behaviour of CFRP strengthened CHS (1). B.Rajesh Babu and M.C.Sundarraja (2017), Strengthening of HSS Tubular Sections Using CFRP Strips. HSS tubular sections are the

most versatile and efficient form of construction industry. The suspended behavior of HSS tubular members can be brought back to it by strengthening. The strengthening technique with carbon fibre reinforced polymer (CFRP) in the steel structures is more advanced than the traditional approaches of strengthening (2). N. Elangovan and P. Srirama (2016), the Study on Strengthening of Hollow Steel Section by Using CFRP and AFRP. Retrofitting of the structure is better alternative instead of whole replacement of structure. Retrofitting by using CFRP and Aramid fiber reinforced polymer (AFRP) has been increasing interest (7). P. Gowri and, B. Shanmugavalli (2017), Study on Experimental Investigation on the Buckling Behaviour of Steel Tubular columns using CFRP. Recently, CFRP is being used for metallic structures. The purposes of using CFRP materials are i) High Strength to Weight ratio ii) Better durability in worst environment. It increases load carrying capacity and improves stiffness and buckling behaviour of structure (8). J. Sahaya Jeeva Rethnam et al (2017), Performance of BFRP and GFRP Hollow Circular Steel Columns Subjected to Axial Compression Loads. Recent research has been focused on rehabilitation and strengthening of deteriorated steel structures and bridges using Fiber Reinforced Polymer (FRP) materials (9). Sivaganesh Selvaraj et al (2016), Enhancing the structural performance of steel channel sections by CFRP strengthening. This paper presents aim of this test study was to achieve an in-situ strengthening technique to retrofit the deteriorated tall steel structures using carbon fibre-reinforced polymer (CFRP) (10).

2. MATERIAL PROPERTIES

2.1 Hollow Circular Steel Column

The cross section of HCS columns of 200 mm diameter were used for both numerical modelling and experimental testing. The cross sections used as per the code EN 10219-2-2006. The thicknesses of the columns are 2 mm and length of the column 800mm. it is shown in figure 1. The aspect ratio of the column is 4 for cross sections. The cold formed steel of 235 grades is used. The Poisson's ratio for the used steel is 0.3 and young's modulus is 200Gpa and 210Gpa for cold formed steel section.

2.2 CFRP Laminate

Normally, the CFRP materials have been extensively used for strengthening structural steel elements because of their high tensile strength. The CFRP used in this study is a normal modulus CFRP laminates. There are two types of CFRP is used but there thickness are different. That was CFRP 450Gsm and 250Gsm. The fibre is unidirectional with thickness and width of the fibre as 0.2 mm and 500mm respectively. It is fabric type and can be tailored into any desired shape. Figure 2 shown in CFRP laminates.

2.3 GFRP Laminates

Glass fiber is a material consisting of numerous extremely fine fibers of glass. Glass fiber is commonly used as an insulating material. The GFRP used in this study is a normal modulus GFRP laminates. It is used in most palls used in concrete structures but in this study used for steel sections also. Figure 3 shown in GFRP laminates.

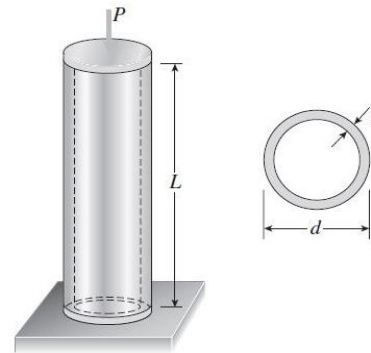


Fig.1 Cross Section of HCS Column



Fig.2 CFRP Laminates Fig.3 GFRP Laminates

2.4 Epoxy Resins

An epoxy resin was used as adhesive material is Nitowrap. These are good bonding material between the steel and FRP laminates. Nitowrap is used for strengthening columns and beams of load bearing structures specifically where improvement to shear strength and deformation properties is required. Epoxy resins having mix ratio of 1:2 by weight such as 1g resin and 2g Hardened. The elastic modulus of epoxy resin is 2.1GPa.



Fig.4 Epoxy Resin

Table.1 material properties

Material	Thickness (mm)	Young's Modulus (N/mm ²)	Yield Strength (N/mm ²)	Poisson Ratio
STEEL	2	2 × 10 ⁵	235	0.3
GFRP	0.3	76 × 10 ³	2200	0.2
CFRP (450Gsm)	0.3	285 × 10 ³	3500	0.3
CFRP (250Gsm)	0.2	235 × 10 ³	2100	0.2



Fig.6 Specimen 2

Fig.7 Specimen 3

2.5 FRP Composite with HCS

The term “composite” refers to the structure combining the matrixed fabric with the synthetic resin. The composite, prepared on site, is made of approximately 60% fabric and 40% epoxy resin. For Epoxy resin primary layer, wrapping of CFRP (450Gsm and 250Gsm) with Epoxy 1st layer, wrapping of GFRP (450Gsm) with Epoxy of 2nd layer, wrapping CFRP with Epoxy 3rd layer.

3. DETAILS OF THE TEST SPECIMENS

There are two types of specimens are analysed

- a. Specimen 1 (HCS)
- b. Specimen 2 (HCS + CFRP 450Gsm + GFRP + CFRP 450Gsm) with epoxy resin
- c. Specimen 3 (HCS + CFRP 250Gsm + GFRP + CFRP 250Gsm) with epoxy resin

4. EXPERIMENTAL PROGRAMME

All the column specimens are 200 x 2mm were manufactured in the rolling machine. The length of column used is 800mm. The hollow circular section column is made by the following cold formed steel of 2mm thicknesses is first cutted according to the appropriate sizes for rolling the sheet in the press machine. The circumference for the cross section 200 x 2 mm was calculated 628.57mm respectively.

4.1 Specimen Preparation

The 200×2 mm HCS specimens were 800 mm long. The surface of the steel specimens were first roughened by sand blasting and then scrubbed by sand paper to remove the corroded particles in steel and to get better bonding between steel specimen and fibers.



Fig.5 FRP wrapping with HCS column

Afterwards the sand blasted surface of the steel substrate was cleaned by acetone to eradicate all contamination before wrapping with the fibers. Prior to the specimen strengthened by different type of fibers, one thin coat of Nitowrap primer was applied. Then the carbon fibers and glass were wrapped to the external surface of the hollow circular steel specimens with different wrapping. FRP wrapping with HCS column shown in, figure 6 is CFRP 450 and figure 7 is CFRP 250 in showed.

4.2 Instrumentation

The hollow circular steel columns were tested in universal testing machine of capacity 1000 kN, It's shown in figure 8 bellow. The experimental set up is Earlier to apply loading, the specimens were positioned on the support and also centered to make sure that the two supporting ends were parallel to each other and at right angles to the loading axis. The load was applied to the column by hydraulic jack and monitored by using 1000 kN capacity load cell. Axial deformation of the column was measured using linear voltage displacement transducer (LVDT) which was kept at center of the jack. At the beginning, 10% of the estimated load (25KN) was applied slowly, so that the columns settle properly on their support. The deformation of fibers were carefully recorded and tabulated which also include the stress, strain and percentage of change in length of the specimens. The load at which the fiber starts rupturing and the nature of failure were also noted for each column.



Fig.8 Universal Testing machine with specimen

4.3 Failure Modes

All the specimens were tested to observe under ultimate loading and displacement. The reference specimen 1 and 2 were designated as Trial 1, Trial 2, Trial 3, etc... and were tested with the same loading and boundary conditions under compression.



Fig.9 failure modes

As can be seen, all strengthened control specimen exhibited a distinctive buckling failure. This failure looks like an elephant foot's buckling. This failure is proved as the past researches. Failure mode of specimens an outward buckling deformation near by a local buckling occurred at the top and bottom end of the specimen was noted. The failure modes are below figure 9.

5. RESULT AND DISCUSSION

The experimental observations are tabulated in Table.2

Table.2 observations Values

Specimens types		Critical Load (kN)	Displacement (mm)	Stress (N/mm ²)	Strain
(HCS)		265.8	3.41	209.4	0.00426
CFRP 450Gsm	Trial 1	359.2	3.48	283.0	0.00431
	Trial 2	358.4	3.37	282.3	0.00447
	Trial 3	356.2	3.41	280.6	0.00405
CFRP 250Gsm	Trial 1	305.1	3.25	240.3	0.00395
	Trial 2	303.7	3.21	239.2	0.00338
	Trial 3	306.7	3.19	241.6	0.0041

5.1.1 Load carrying capacity

From the graph it was evident that all the specimens wrapped with FRP showed a considerable increase in ultimate load carrying capacity over the HCS specimens. In the CFRP 450Gsm (Trial 1, Trial 2, Trial3), a noticeable elephant's foot buckling fold at the bottom and top end was observed FRP was occurred at the loads of 359.2 kN , 358.4 kN, 356.2kN and the displacement of 3.48mm,3.37mm,3.41 mm respectively. The average

ultimate load is 357.9kN displacement 3.42mm it has been taken into the value of CFRP 450. In the CFRP 250Gsm (Trial 1, Trial 2, Trial3), a noticeable elephant's foot buckling fold at the bottom and top end was observed and crushing of FRP was occurred at the loads of 305.1kN, 303.7kN, 306.7kN and the displacement of 3.25mm, 3.21mm, 3.19mm respectively. The average load is 305.1kN displacement 3.21mm it has been taken into the value of CFRP 250.

5.1.2 Displacement Control

The control of deformation is clearly observed in strengthened columns when compared with CFRP 450Gsm to 250Gsm. The CFRP as a strengthening material efficiently delays the buckling and hence significantly controls the displacement of HCS. From the observed experimental results it has been evident that the displacement control is changed for all the trials. The specimens are compared the displacement at maximum and minimum ultimate load points specimen 1 is 3.41mm and 3.48, specimen 2 is 3.21 and 3.29. The displacement controlled with 5%-8%. The displacement control for with the increase in FRP thickness it was observed. The reason is attributed to the reduction in FRP confined area in those cases. The load carrying capacity increased the displacement also increased. Figure 11 shown in Critical Displacement CFRP 450 vs. CFRP 250.

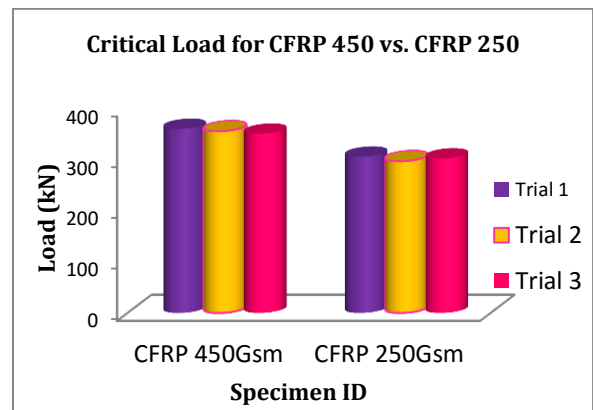


Fig.10 Critical Load for CFRP 450 vs. CFRP 250

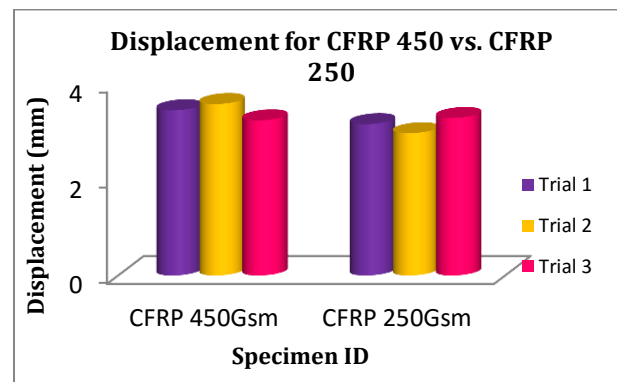


Fig.11 Critical Displacement for CFRP 450 vs. CFRP 250

5.1.3 Stress vs. Strain behaviour

The axial stress -strain behaviour of specimen CFRP 450Gsm and 250Gsm wrapped column specimens under axial compression is shown in figure 13 From the stress -strain curves of all columns, it was observed that, there exists linearity in the graph until the failure load and thereafter the graph shows non-linearity and the reason is that resin starts crushing at the failure load When the fibre started rupturing, there was a sudden return in load transfer. Until the load of 360.2kN is reached, there exists a consistency in the stress-strain behaviour of all columns. Afterwards the inconsistency observed is attributed to increase in CFRP 450Gsm.

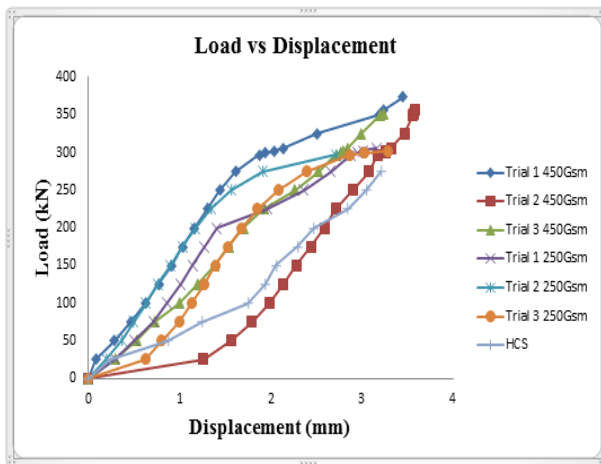


Fig.12 Load vs. Displacement Curve for Specimens

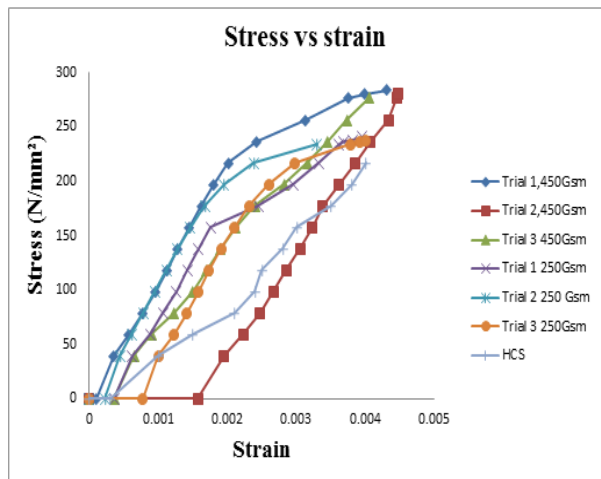


Fig 13 Stress vs. Strain Curve for Specimens

5.1.4 Ductility Factor

Ductility factor is defined as the ratio between the ultimate deformation and the yield deformation which is calculated from the stress- strain diagram of all columns. Ductility of a column is its ability to sustain inelastic deformation without loss in its load carrying capacity prior to failure. Ductility can be expressed in terms of

deformation or energy. The deformation can be deflection, strain, or curvature. The yield point load of the CFRP 450 (Trial 1, Trial 2, Trial 3) is 325kN, 325kN, 300kN. The displacement at the specimens 2.51mm, 3.47mm, 2.76mm. . The yield point load of the CFRP 250 (Trial 1, Trial 2, Trial 3) is 225kN, 275kN, 275kN. The displacement at the specimens 1.96mm, 1.91mm, 2.3mm. Ductility of HCS wrapped columns are presented in below Table 3.

The ductility definition based on deformation reflects the actual physical behaviour of columns. It is evident that the ductility factor generally decreases with the increase in thickness of the FRP. From the graphs that ductility of 450Gsm wrapped specimens are higher in general when compared with 250Gsm wrapped specimens. The influence of D/t ratio plays good in the aspect of ductility.

Specimen ID		Energy Ductility	Displacement Ductility	Buckling Model
CFRP 450Gsm	Trial 1	1.10	1.37	Outward buckling at top
	Trial 2	1.09	1.03	Outward buckling at top
	Trial 3	1.17	1.09	Outward buckling at bottom
CFRP 250Gsm	Trial 1	1.36	1.61	Outward buckling at top
	Trial 2	1.08	1.55	Outward crushing at bottom
	Trial 3	1.10	1.38	Outward buckling and inward buckling at bottom

Table.3 Ductility Indices of Tested Specimens

5.2 GEOMETRIC IMPERFECTION

Imperfection of steel members is very important as it reduces the capacity of the member. There are two types of local imperfection and global imperfection. The local imperfections mainly affect the local or distortional buckling capacities while global imperfection mostly affects the member capacity. Local imperfection is expressed in terms of dimensions of the section and thickness while global imperfections are expressed in terms of member length. In this study paper the local imperfection has been achieved. This type of column buckling is also called as Elephants' feet buckling. It is the named after a geometrical shape or design typical of Turkmen rugs, are the ends of the main suction pipe in cargo tanks of tankers that are prone to corrosion degradation.

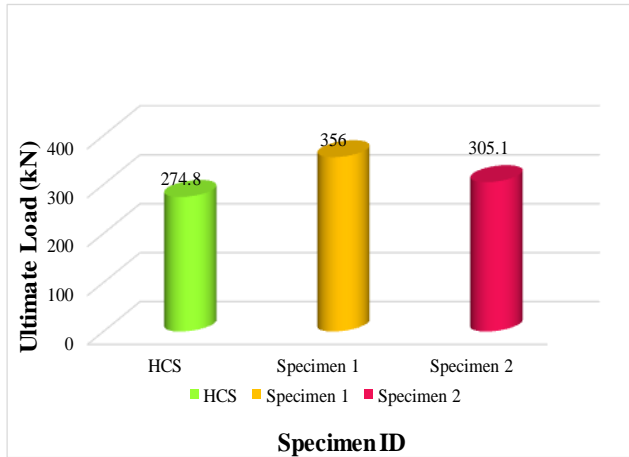


Fig.14 Ultimate Load of the Specimens

6. CONCLUSION:

From the experimental study, the following conclusions are made.

- The preliminary works such as literature survey is observed that the use of FRP confinement greatly enhances the load carrying capacity of hollow circular steel column and the maximum axial deformation is also significantly controlled by the confinement of FRP layers.
- Adding GFRP laminates additionally in between the CFRP. The comparison of finite element analysis and experimental testing carried out (3 Trials) for the critical load. When the specimens the wrapped section specimen 1 giving the high strength, displacement is low and delay the bulking.
- The (CFRP 450 +GFRP) wrapped columns showed a significant increase in load carrying capacity when compared to the control column to the minimum values in the range of 25% - 32%, while The (CFRP 250 +GFRP) wrapped column showed 8%- 15% increase in axial load capacity when compared to control specimens.
- The decrease in deformation corresponding to the ultimate load of control specimen was much greater in case of (CFRP 450 +GFRP) strengthened specimens over (CFRP 250 +GFRP) strengthened columns. CFRP + GFRP also increases the strength compare to CFRP double wrapping. It is low cast compare to CFRP laminates.
- This is structure increased the life of the structure. It's mostly used in high-rise buildings, steel frames, and steel bridges. These FRP laminates can be used to avoid the heavy damage before the complete failure of the structure. This FRP laminates can be used for rehabilitation works.

7. FUTURE SCOPE:

Further this study paper can be continued by the use of hollow circular section with concrete infill tubular section, wrapping with FRP. The role of the concrete core is not only to resist compressive forces but also to reduce the potential failure of local buckling by the steel sections. Compare to CFRP and the cost effective other FRP laminates (Aramid, Basalt, Polyethylene) are used to the wrapping which gives the high strength to be calculated. In this study axial loading and axial displacement tested, to contusive the study tests the lateral displacement and lateral load.

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