Experimental Study on Behaviour of Concrete Filled Steel Tubular Columns

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Abstract— Study the comparison on behavior of circular CFST columns and HST (Hollow Steel Tube) columns under uniaxial compression. A total of twenty eight specimens were tested in order to analyze the behavior of CFST columns. The effect of same D/t ratio and changeable L/D ratio on the behavior of CFST columns, ductility and failure modes for mild steel tube and stainless steel tube is experimentally investigated. The columns were proven to have certain shortcomings such as ageing of structures, corrosion of steel tubes. Therefore, the implementation of strengthening techniques with the new material is necessary to eliminate this difficulty. So conducted an experimental revise on CFST column wrapped with GFRP strips by varying wrapping width to space width as two, under axial loading.

Keywords— CFST members, circular, compression, GFRP composites, slender, strengthening

1 Introduction

Concrete-Filled Steel Tubes (CFSTs) are composite members consisting of a steel tube infilled with concrete. A CFST member utilizes the advantages of both steel tube and concrete through the composite action. CFST structure offers numerous structural benefits, including high strength and fire resistances, favorable ductility and large energy absorption capacities. In recent years, many steel and CFST structures have been found to be suffering from a variety of deteriorations; these deteriorations are caused by a variety of factors, including fire, ageing, environmental degradation and corrosion. There are several strengthening or rehabilitation techniques that can be applied to enhance performance, including section enlargement, external bonding using steel plates and fibers, among others. The external strengthening of structures using steel plates had some problems due to the addition of weight, corrosion of the steel plate, the need of skilled labour and the higher cost. In contrast, use of Fibre Reinforced Polymer (FRP) composites for rehabilitation does not have any of these drawbacks. One of the main forces driving the development of external strengthening methods that uses the FRP composite is that they enable deteriorated members to be upgraded without significantly altering the appearance of the member. In addition, FRP composites are light weight, durable, and resistant to corrosion, and have high tensile strength, stiffness and fatigue strength. In recent years, there have been many investigations on the use of FRP to strengthen the steel structures emerged, particularly in the area of thin-walled steel structures.

The main objective of this paper is to experimentally investigate the behaviour of CFST and HST columns in axial compression for varying *L/D* ratios and steel type and the feasibility of the utilization of GFRP composite strips in strengthening circular CFST columns, and attention was also paid to compare the effectiveness of different FRP wrapping schemes. The experimental parameters were the number of GFRP layers and provided the spacing between the FRP strips as wrapping width to spacing width of two.

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2 Materials Property

The circular hollow mild steel and stainless steel tube having an outside diameter of 60 mm was used in this study. The thickness of the circular hollow steel tube was about 3.0mm and the height of the stub column was maintained as 600mm and 800mm. The yield strength of the mild steel and stainless steel tube was 250N/mm^2 and 502 N/mm^2. The concrete mix proportion was designed using the IS method to achieve strength of 20N/mm^2, and the mix ratio was 1: 2.04: 2.190 by weight. Ordinary Portland cement was used in this study as a binding material. The specific gravity of the cement was tested, and was found to be about 3.03. The M-sand passing through 4.75 mm was used as fine aggregate. The specific gravity of the sand and the coarse aggregate was about 2.61 and 2.79. Concrete cubes specimens were cast for each batching and tested at the age of 28 days to determine the compressive strength of the concrete. The average compressive strength of the concrete was about 31.97N/mm^2. A GFRP was used to strengthen the CFST which has an Elastic Modulus value of 51000N/mm^2 and tensile strength of 1600N/mm^2. An epoxy bonding agent (Polyester Resin) is used in this study to obtain sufficient bonding between steel tube and glass fibre. Random direction matts was used in this study.

3 Experimental Investigation

3.1 Specimen Fabrication

Circular surface, both ends of the steel tube was leveled using a spirit level. Before filling the tube with concrete, the inside portion was thoroughly wire brushed to remove rust and loose debris. Then the steel tube was filled with concrete, layer by layer and each layer was effectively compacted to ensure the concrete was free from air gap sand flaws. During compaction, a steel plate was introduced at the bottom of the steel tube to eliminate the leakage of slurry, and then the concrete was allowed to cure for 28 days. The hollow steel tube specimens and concrete filled specimens of mild as well as stainless steel tube (16 specimens) were tested under axial compression. After curing, all the rest (12 specimens) CFST members were subjected to sandblasting using coarse sand to remove the rust and to make the surface rough one. Before the columns were strengthened with GFRP composites, acetone was used to clean the surface to remove the contaminated materials. Finally, the members were strengthened with GFRP composite, using different wrapping schemes and layers. The wrapping scheme is shown in Fig.1. During wrapping, a steel roller was used in the direction of the fibre to remove air gaps and excess resin.

3.2 Description of Specimen

Among 28 specimens, 16 columns were tested without strengthening. The experiment is carried out for 60mm diameters with two lengths (600mm and 800mm). The experiments are carried out for same D/t ratios 20. Effect of L/D ratio is studied by conducting experiments for two L/D ratios (10 and 13.33). As a result, HST1, CFST1, HSST1 and CFSST1 fall into the category of short columns and HST2, CFST2, HSST2 and CFSST2 fall into the category of slender columns. Hollow steel tube, Concrete filled mild steel tube, Concrete filled stainless steel tube column elements are designated as HST, CFST and CFSST respectively. The abbreviations are followed by one number; the number denotes the length of the tube (1 for 600mm, 2 for 800mm). The next 8 columns of mild steel tube were externally bonded with GFRP having a constant width of wrapping to spacing ratio of 2. The remaining 4 specimens were fully wrapped for strengthen. To identify the specimens easily, the columns were designated with names such as CFST1-F-a, CFST1-L-a, CFST1-L-b, CFST2-F-a, CFST2-L-a, CFST2- L-b.

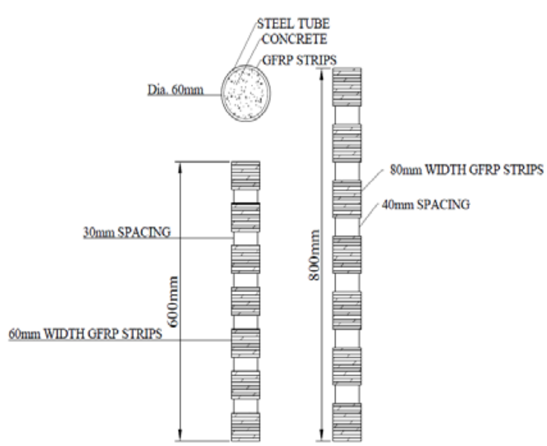


Fig. 1: Wrapping Scheme

Specifies that "CFST" concrete filled steel tube of 60mm diameter, "1" equal to 600mm height column, "2" equals to 800mm height column, "L" equals to wrapping as strips keeping that width of wrapping to spacing provided as two, "F" equals to wrapping full on the specimen "a" equals to providing a single layer, "b" equals to providing a two layer.

3.3 Experimental Setup

All columns were tested in a Universal Testing Machine of 600kN capacity. Each member was positioned on the supports, taking care to ensure that its centerline was exactly in line with the axis of the machine. The specimens were instrumented to measure the longitudinal axial compression. The axial deformation of the column was measured using a dial gauge which was kept on top of the jack. At the beginning, a small load of 20kN was applied slowly, so that the columns could settle properly on their supports. The column was then tested to failure by applying the compressive load in small increments, and observations of occurrences such as axial deformation and ultimate load were carefully recorded. The load at which the GFRP starts rupturing and the nature of failure were also noted for each column. The axial loading setup is shown in Fig. 2.

Fig. 2: Experimental setup

4 Results

4.1 Failure mode

Un-Strengthened Columns

The failure modes of short and long columns were observed. The long columns failed due to overall flexural buckling whereas the short columns failed by crushing of concrete accompanied by the yielding of steel. The short column specimens after loading are shown in Fig.3:(a),(b) and long column specimens are shown in Fig.4:(a),(b). It can be clearly observed that CFST specimens undergo significant lateral deformation compared to hollow steel tube and these buckle at mid-height of the section.

(a) (b)

Fig. 3: Specimens after loading (a) HST1 and CFST1, (b) HSST1 and CFSST1

(a) (b)
Fig. 4: Specimens after loading (a) HST2 and CFST2, (b) HSST2 and CFSST2

Bulges were observed near the top ends of the columns (referred to as elephant foot formation) of short columns which indicate outward local buckling. The reason for this is, that steel tube is pushed out by the concrete core. The effect of different steel type on the CFST was observed using the short and long column specimens. It can be inferred that the bulge was prominent in the case of mild steel specimen especially in short column. This is clearly depicted in Fig. 5:(a), (b). The significance of bulge formation on the performance of CFST columns need to be further investigated.

(a) (b)
Figure 5: Effect of steel type (a) Mild steel (b) Stainless steel

Strengthened Columns

In the initial stage, large deformation was observed in unstrengthened columns (CFST1 and CFST2) because of the uneven concrete surface at the top of the column after that the applied load was approximately proportional to the axial deformation; in addition, there were no obvious changes in the appearance of the specimens. Loading further, buckling of the steel tube occurred near to the mid-height and top and bottom support of the column. The presence of concrete, effectively delayed the inward buckling of the column, and the bulge near the mid-height of column in Fig.6 is clear evidence of outward local buckling. In CFST columns bonded with one layer fully wrapped with GFRP (CFST1-F-a and CFST2-F-a), yielding of the steel tube was observed near the mid height of the column. Finally the columns failed when buckling occurred. However, no rupture of fibre was observed, as shown in Fig.7.

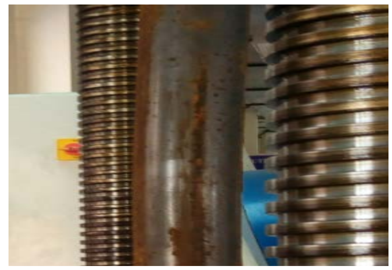


Fig. 6: Failure mode of CFST1

In all the other columns which the wrapping is done by layered it was observed that the origin point of the buckling was the un-bonded area. When the columns confined with GFRP strips (CFST1-L-a and CFST2-L-a), the zone confined with GFRP strips become more rigid due to the greater confinement pressure exerted by the GFRP strips. As a result the buckling of steel tube occurred without any rupture of fibre.

Figure 7 Failure mode of CFST1-F- a, CFST2-F-b

When the number of layers was increased, the failure mode of the columns (CFST1-L-b and CFST2-L-b) was transformed to yielding of steel tube followed by rupture of fibre, as shown in Fig.8.

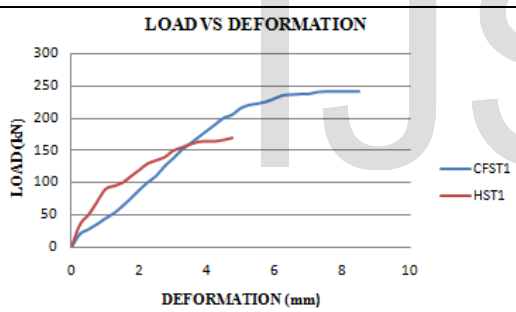
Fig. 8: Failure mode of CFST2-L- b

This is a result of the fact that, the increase in the slenderness value (d/t) by bonding GFRP composites of the steel tube delayed the yielding of the steel tube, and effectively increasing the stability of the columns. In addition the bonded GFRP strip, makes the steel tube near to the GFRP strips become more rigid due to the greater confinement pressure exerted by the GFRP strips and counteract the outward buckling of the steel tube. When the GFRP strips no longer to resist the lateral expansion of the steel tube, rupture of GFRP occurred, followed by buckling tube occurred. It has been noted that, in all of the above specimens, no de-bonding of fibre was observed before ultimate load, and thus it was confirmed that there was a perfect bond between the steel and GFRP.

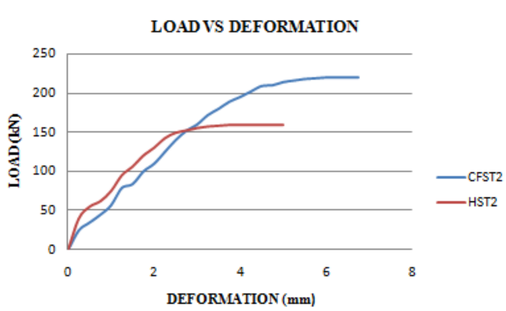
4.2 Load deformation curve

Un-Strengthened Columns

The behaviour of hollow steel tube and concrete filled steel tube can be observed by plotting the load deformation curve. The comparison of performance of 60mm diameter mild steel specimen for short and long column is shown in Fig.9 (a) and (b). It can be observed that the ultimate load carrying capacity increased in case of the CFST specimen. It can also be noted that the deformation of the CFST specimen after the yield load is much more compared to the hollow steel specimen.



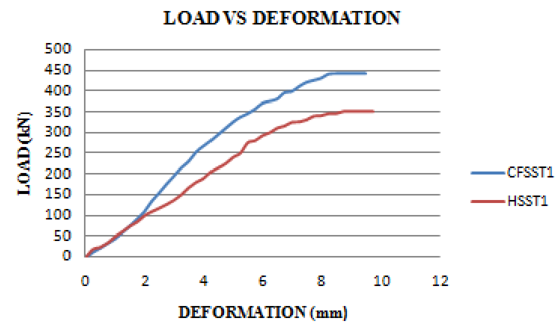
(a)



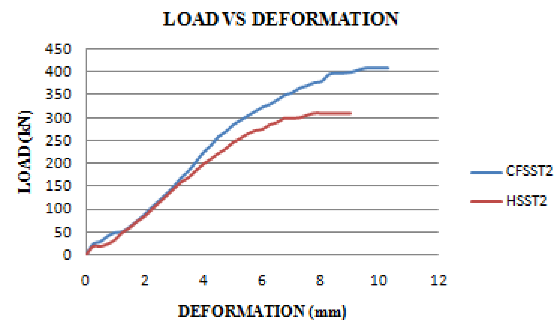
(b)

Fig. 9: Load deformation curve of 60mm dia. Mild steel specimen (a) short column (b) long column

The comparison of performance of 60mm stainless steel specimen for short and long column is shown in Fig.10 (a) and (b). It can be observed that the ultimate load carrying capacity and stiffness increased in case of the CFSST specimen.



(a)



(b)

Fig. 10: Load deformation curve of 60mm dia. Stainless steel specimen (a) Short column (b) Long column

Comparison based on steel type:

The experiment is conducted for two different steel types (Mild steel tube and stainless steel tube). Load deformation curve of HST and CFST with different steel type for short and long column is plotted and compared in Fig. 11. It can be observed that as yield strength (fy) increases the ultimate load carrying capacity increases.

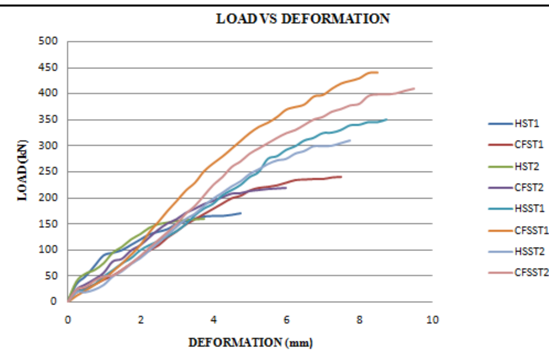


Fig. 11: Load deformation curve for different steel type

Strengthened Columns

The behaviour of CFST and GFRP wrapped strengthened CFST specimens can be observed by plotting the load deformation curve. The comparison of performance of 60mm specimen for short column is shown in Fig.12. It can be observed that the ultimate load carrying capacity increased in case of the CFST1-L-b specimen. It can also be noted that the deformation of the GFRP wrapped specimens after the yield load is much less compared to the un-strengthen CFST specimen.

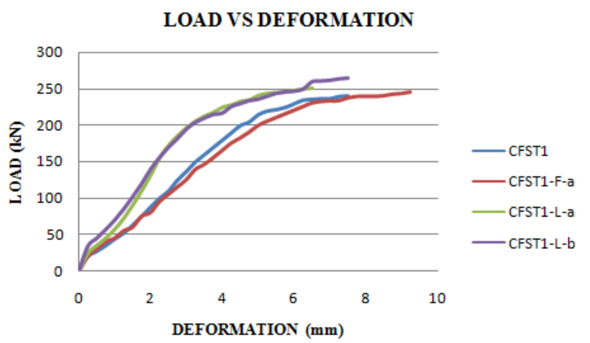


Fig. 12: Load deformation curve of short CFST specimen

The comparison of performance of 60mm specimen for long column is shown in Fig.13. It can be observed that the ultimate load carrying capacity increased in case of the CFST specimen wrapped with strips by providing a wrapping width to spacing as two.

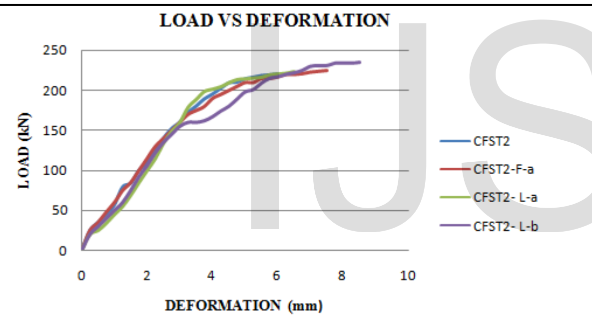


Fig. 13: Load deformation curve of Long CFST specimen

Comparison based on L/D ratio:

The experiment is conducted for two L/D ratios (10 and 13.33). Load deformation curve of CFST and the CFST columns strengthened with different wrapping scheme is plotted and compared in Fig.14. It can be observed that as the L/D ratio increases the ultimate load carrying capacity decreases for strengthen and un-strengthened columns.

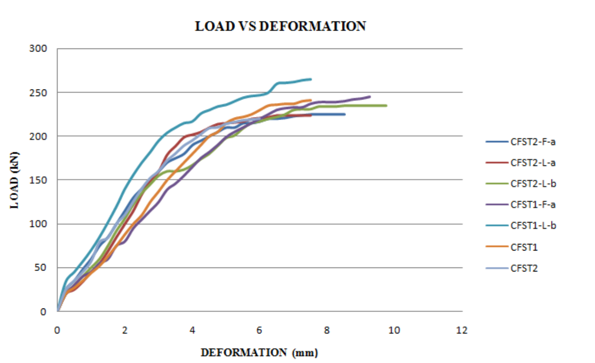


Fig. 14: Load deformation curve for different L/D ratios

5 CONCLUSIONS

With reference to the experimental study carried out throughout the work, certain conclusions are drawn. They are summarised as follows:

- Load deformation curve of concrete filled steel tubular columns clearly indicated improved ductility when compared to hollow steel tube columns. Short columns were found to fail by crushing of concrete accompanied by the yielding of steel and long columns failed due to overall flexural buckling. When the concrete filled steel tubular short columns are loaded axially, formation of bulges was observed at the top of the specimen which was observed to be a trait in short column alone.
- From the experimental studies, it can be seen that the ductility index decreases for the stainless steel tube with concrete filled when compaired to mild steel tube with concrete filled
- The column confined with two layers of GFRP strips by providing a wrapping width to spacing width of two showed more restraint effect against the lateral deformation of the column, and enhanced their axial deformation control and load carrying capacity, when compared to the CFST columns and CFST columns fully wrapped.
- The rupture failure mode of the GFRP does not affect the ductility performance of columns, in addition the presence of GFRP enhanced the ductility of the columns, especially the column confined with two layers in provided spacing.
- It is suggested that GFRP provided full and having a spacing of wrapping width to spacing width of two is suitable for CFST column strengthening subjected to axial compression; however, the column strengthened with spacing provides economical strengthening compared to the column with no spacing.

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