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Load Bearing Capability of CFST Columns with and without Shear Connectors

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ABSTRACT:
Normally the concrete columns subjected to major loads will buckle and fail, to avoid this buckling phenomena the use of concrete filled steel tube columns are required. Because they do not require formwork. When we provide the shear connectors in the concrete filled steel tube column the lateral displacement of CFST columns is ignored and the bond strength between the concrete and steel is increased. So the investigation is to be carried out by using L/D ratios and by different grades of shear connectors, and finding out the axial compression test and push out test. The L/D ratios are 1.5 and 1.75 and the grade of shear connectors 7.8 and 8.8 are used, but the good results are obtained at the L/D ratio of 1.75 and 8.8 grade size of shear connectors, and the strength parameters with and without shear connectors in CFST was found and its value is increased to 18% when shear connectors are provided.

Keywords: CFST columns, shear connectors, axial compression test.

1. INTRODUCTION

Concrete filled steel tube columns are widely used in the construction of bridges, high-rise buildings, barriers and subway platforms. Because they offers numerous structural benefits including high strength and fire resistance and large energy absorption.

The concrete filled steel tube columns combine the benefits of both concrete core and steel tubes. The steel tube confines concrete core in it, so there is no need for the use of shuttering during concrete construction; hence the construction cost, labor work and time are reduced. The principle preference of the concrete in CFST was because it can reduce the local buckling of the steel tube and it has the capacity to support higher stress and strains than when the segments was uncontrolled.

1.2 BEHAVIOR OF CONCRETE FILLED STEEL TUBE (CFST)

Many studies have shown that the performance of a square concrete-filled steel tube (CFST) is not as good compare to its circular counterpart. This is due to the fact that a square steel tube could only provide less confining pressure to the concrete core, and that its local buckling is more likely to occur. This fact has now been widely reflected in modern design codes such as Manual of Steel Construction. Load and Resistance Factor Design (LRFD) (AISC 1994) and Seismic Provisions for Structural Steel Buildings (AISC 1997), Design of Composite Steel and Concrete Structures, Euro code 4,ENV 1994-1-1 (BSI 1994), and Recommendations for Design and Construction of Concrete-Filled Steel Tubular Structures (AIJ 1997). Allowable width-to-thickness ratio for the steel tube with square cross-section is more restricted than that for circular one. Accordingly, an adequate stiffening measure for square CFST is highly desirable. Such stiffening measure will make square CFST an economical construction material, too, and consequently the barrier to promote construction using square CFST could be overcome.

The structural behavior of CFST elements are considerably affected by the difference between the Poisson‘s ratios of the steel tube and concrete core. In the initial stage of loading, the poisons ratio for the concrete is lower than that of steel. Thus, the steel tube has no confining effect on the concrete core. As longitudinal strain increases, the lateral expansion of concrete gradually becomes greater than expansion of steel tube. At this stage, the concrete core becomes tri-axially and steel tube bi-axially stressed. The steel tube under a biaxial state cannot sustain the normal yield stress, causing a transfer of load from tube to the core. The load transfer mechanism is similar for square and circular CFST elements. In the first stage of loading the steel tube sustains most of the load until it yields shown in the figure 1. At this point (a) there is a load transfer from steel tube to the concrete core. The steel tube Exhibits a gradual decrease in load sharing until the concrete reaches its maximum compressive strength (a to b). After this stage of loading (point b), there is redistribution of load from concrete core to the steel tube. At this point (b) the steel exhibits a hardening behavior with almost the same slope as in uni-axial stress-strain hardening relationship.

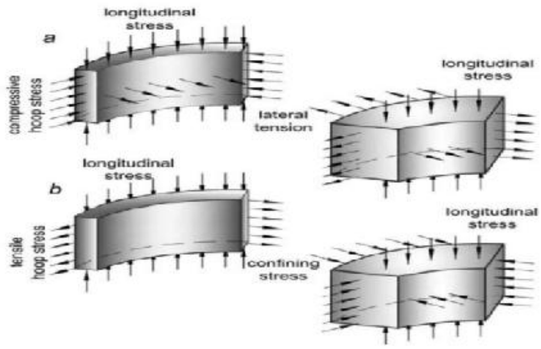

Figure.1 Stress condition in steel tube and concrete core at different stages of loading

1.3 OBJECTIVE OF THE STUDY

A good structural system must be evaluated in four aspects; the cost performance, the fabrication, the quality assurance, and the structural performance. The objective of this research is

- To study the bond stress characteristics of concrete and steel tubes in the structural performance with or without the addition of shear connectors
- To study the maximum axial load bearing capacity of the concrete filled steel tubular columns with and without shear connectors
- To study the influence of shear connectors in the ductility performance in the CFST columns

2. LITERATURE REVIEW

Baskar et al. (2012), investigated the bond stress characteristics on circular concrete filled steel tubular columns using mineral admixture metakaoline. The previous study on this subject reveals the behavior and strength of circular concrete filled steel tube columns with the diameter-to-thickness ratio of 34 to 51, filled with the high-strength concrete of (34 to 103Mpa). The results of these tests were exhibit very high levels of energy dissipation and ductility. Though researches made push out test of CFSTs have been carried out for many years. And also include the work of experiments on concrete filled steel tubular columns by the use of fly ash was studied. From these researches, bond strength and compressive strength of CFSTs can be improved by adding fly ash. The test results reported that light weight aggregate concrete offered higher bond strength and compressive strength than normal concrete, but load-slip behavior of all specimens is similar for both type of concrete. It is well known that the strength of ordinary Portland cement concrete is significantly influenced by the replacement of cement with mineral. In the last 12 years, a new material metakaoline is being studied because of its high pozzolanic properties. Owing to its fineness and chemical composition, metakaoline shows closer behavior to silica fume. Many investigations have focused on the behavior and strength of CFST columns using fly ash and expansive agent. In this study use of metakaoline to the concrete of CFSTs to improve the bond strength and compressive strength of the concrete was experimentally investigated. Based on the results of these investigations, the following conclusion is obtained. Adding mineral admixtures like metakaoline to the concrete is effective in increasing the member ductility and also effective in ultimate strength of the CFST columns. It was observed that the bond carrying capacity decreases with increasing in percentage of metakaoline but increases up to 15% of metakaoline in concrete.

Gengying et al. (2005), investigated the behavior of concrete-filled steel tubular columns incorporating fly ash. The previous studies on this subject reveals the presence of silica fume or fly ash produces a more homogeneous microstructure by balancing the Ca/Si molar ratio in the interfacial zone relative to that in the bulk paste, quite different from ordinary Portland cement concrete, where this ratio increases dramatically as the aggregate surface is approached interface between steel tube and concrete has a similar structure as that of normal aggregate and paste. In this paper, the effect of fly ash on the microstructure of the interface between concrete and steel tube after 1 year curing was experimentally investigated by using both Scanning Electron Microscopy (SEM) analysis and Energy Dispersive Spectroscopy (EDS) analyzer. The microstructure of the Center zone for both the high-volume fly ash concrete filled steel tubular columns (40 wt%) (FCTs4) and the high-volume fly ash concrete (40 wt%) (FCC4) after 365 days curing was also studied. And the results found as the early strength is weakened when high-level fly ash is incorporated; however, the ultimate strength is significantly improved, and the improvement of strength leads to a higher stiffness and a better resistance to local bucking for concrete filled steel tubular columns when fly ash was used.

Georgios et al. (2000), investigated the behavior of circular concrete-filled steel tubes (CFST) with various concrete strengths under axial load is presented. The effects of steel tube thickness, the bond strength between the concrete and the steel tube, and the confinement of concrete are examined. Measured column strengths are compared with the values predicted by Euro code 4, Australian Standards and American Codes. All three codes predicted lower values than that measured during the experiments. Author suggested ACI and AS code to take the confinement effect in to account also give a value also show the different of load displacement behavior in greased and non-greased inner surface. Author indicated that Euro code 4 provides a good prediction of the axial strength of concrete filled steel tube columns, 17% was the largest difference between the experimental and calculated value on the axial capacity. Excellent prediction was achieved for high strength CFSTs, with 'n' number of tests/NEC4 ratio around unity. The predicted axial strengths using ACI and AS were 35% lower than the results obtained from experiments. A coefficient is proposed for the ACI/AS equations to take into account the effect of concrete confinement on the axial load capacity of CFSTs. The effects of the bond between the concrete and the steel tube is more critical for high strength concrete. For normal strength concrete, the reduction on the axial capacity due to the loss of bonding between steel and concrete is negligible. Euro-code 4 gives the best estimation for both CFST with normal and high strength concrete.

3. MATERIALS

3.1Cement:

OPC of 53 grade is conforming to IS: 8122-1989 was used for the present experimental investigation.

3.2 Fine Aggregate:

Natural river sand with fraction passing through 4.75 mm sieve and retained on 600µm sieve confirming to gradation zone –III was used as fine aggregate. The fineness modulus of sand is 2.81was found in the lab. and specific gravity of sand is 2.65 and these values are satisfied to code book

3.3 Coarse Aggregate:

Crushed granite of size ranging 20mm – 10mm was used and specific gravity was found to be 2.74.

3.4 Water

Potable tap water available in the laboratory was used for mixing of concrete and curing.

3.5 Admixture

In order to increase the workability of the mix ,Super plasticizer CONPLAST SP430 (G) complies with IS: 9103:1999 and BS: 5075 (Part 3) and ASTM-C-494 type 'F' having a specific gravity of 1.220 to1.225 with a pH > 6 which is in Light Brown color was used as a high range water reducing agent. Air entrainment of Approx. 1% additional (As per Manufacturers manual)

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3.6 Steel tube columns:
Diameter of 172mm , Thickness of 2.5mm and these dimensions are satisfying to Euro code by formulae D/t < 90*235/fy

3.7 Shear connectors:
Bolts with grade 8.8 according to IS 1364-part 1(2002)

Table 1. Details of test specimen

Specimen	Diameter D (mm)	Length L(mm)	Thickness t (mm)	L/D
CFST	172	300	2.5	176
CFSTC	172	300	2.5	176

4. MIX DESIGN

Design mix stipulation according to IS 10262-2009
Grade Designation = M-40
Fine Aggregate = Zone-II
Sp. Gravity Cement = 3.13
Fine Aggregate = 2.678
Coarse Aggregate (20mm) = 2.76
Coarse Aggregate (10mm) = 2.66
Minimum Cement (As per contract)= 400 kg /m3
Maximum water cement ratio (As per contract) = 0.4
Mix proportion:
Water: cement: F.A.: C.A. = 0.4: 1: 1.39: 2.34

5. METHODOLOGY

The steel specimens were cut for the obliged L/D ratio, and the edges were flattened well to obtain a level surface for uniform loading. Bolts of High strength with Grade 8.8 according to IS 1364-Part 1 (2002) of length 60 mm was placed as demonstrated in Figure1.a and utilized as a "shear connector". The bolt shear connector was embedded inside and welded to the external steel surface .The connectors placing and position were adopted as per the particulars given for steel Concrete composite bars in Euro-code-4 (2004).

- Minimum spacing of shear connectors in the direction of shear is 5d, (here 5x12=60, provided spacing is 75mm. Hence safe)
- Minimum, spacing in transverse direction of shear force is 2.5d (here 2.5x12=30, provided is 43mm, hence safe) Where maximum of 800mm can be used. In the course of preparation of the test specimens, the specimens were kept in upright position and the compaction was carried out in layers for maintaining a strategic distance from air voids in concrete. And also for performing push out test for finding bond stress, before the casting of specimens a gap of 50mm left not filled at the top for enabling the movement of concrete within the outer shell at load shown in figure.1b

Figure: 1a,1b

5.1 TEST SETUP AND PROCEDURE

The tests were carried out through a recently raised 3000 kN limit compression testing machine as indicated in Figure.4a and the universal testing machine as indicated in Figure.4b.In order to perform axial compression test, steel plates were made for required dimensions with a small groove exactly at the middle of the plate and steel ball of required dimensions were placed at the center point of the two plates.

Figure .4a Experimental setup for push out test

Figure .4b Experimental setup for axial compression test

5.2 Testing of specimens

Figure.4b demonstrated the testing set up of an axially loaded CFST segment. These sections were pin ended at the closures and the load applied exactly on the C.G of the section. A circular steel collar plates were given at the closures of specimens to exchange the concentric action with no slip. The entire setup was mounted on the compression testing machine of capacity 3000 kN. The specimens mounted with dial gauge at the compression side of the tube in order to record the amount of axial shortening for the given load at regular intervals of deflection .The peak load and its corresponding shortening was noted and compared and tabulated in Table 2. For push out test, a steel circular solid of diameter less than the diameter of the specimen was placed over the specimen in order to provide compression only on the concrete. All the specimens were mounted on universal testing machine of 1000 kN capacity. While performing the test, the specimens were kept inverted and load was applied on the concrete alone using a circular steel solid less than the diameter of the specimen as shown in Figure.4b and the 50 mm gap at the bottom got collapsed and the slip were noted up to the failure load after it attains the peak load. The variation between load and slip was compared and tabulated in Table 2.

6. RESULTS AND DISCUSSIONS

6.1 PUSH OUT TEST

In this test we can find out the bond strength between the steel tube and concrete core.

For this test specimen of 172*300mm was casted, but the top 5mm was unfilled with the concrete to carry out test.

The steel tube is kept inverted in the compression test machine; i.e. top 50mm unfilled concrete tube comes downwards and the plate of diameter less than the steel tube was placed on the top of concrete core and the load of 5kN/sec was applied until the bottom 50mm tube is failed then note down the peak load at the point as P

$$F_b = \frac{P}{\pi}$$

Where P was the failure load, D was the inside diameter of the steel tube and L was the length of the concrete steel interface. Figure 5 shows the load vs slip relationships of CFST and CFST with shear connectors. According to the test results, it can be noticed that the strength of the concrete and load conveying limit of the specimen increases with the provision of shear connector in CFST up to 17%. A sound can be perceptible once the failure load reaches. Then solid body motion of the concrete in relation with steel tube starts with increasing displacements. The failure load of the segments was shown in the Figure.6 .The bond failure was shown in Figure 7.

Table 2. Details of tests specimens and results

Specimen	CFST	CFSTC
Diameter D(mm)	172	172
Length L(mm)	300	300
Thickness t(mm)	2.5	2.5
L/D	1.76	1.76
u (kN)	197.5	234.5
Average ultimate compression load f	9	4
Average bond (N/mm2)	1.218	1.447
Percentage of increment in bond	17	

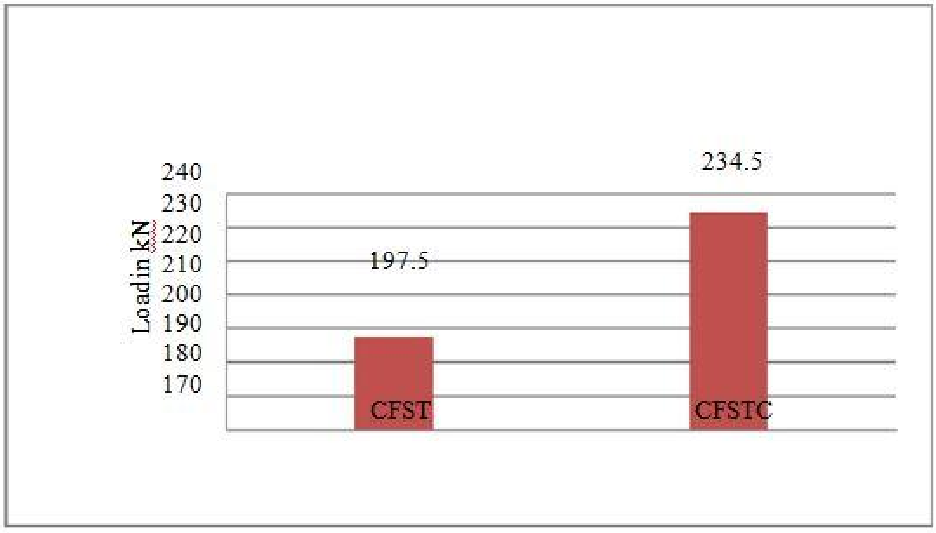

Figure.5 Load vs Slip curves

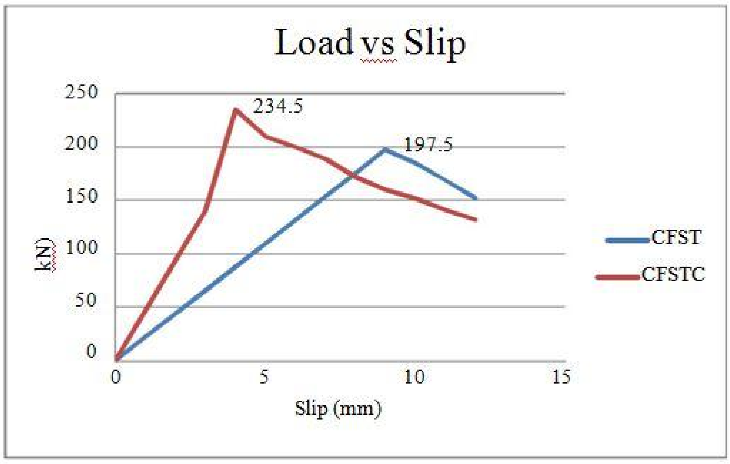

Figure.6 Failure load

6.2 AXIAL COMPRESSION TEST

Graph was plotted between axially applied load and the axial deformation for the CFST segments. The axial load was noted from the compression testing machine while the axial shortening was noted from dial gauge. As the shortening increased further, the micro-cracks in the central solid concrete grew quickly and consequently the Poisson's ratio of concrete increased alarmingly and its value was more than that of steel tube. Subsequently, it actuated the confining pressure, shaping the elasto-plastic branch. For the CFST segments confined with shear connector, the shear connectors induced confining pressure in the beginning and at the absolute starting point, i.e., the starting elastic stage, which could increase the elastic strength of the segments. Figure 7 demonstrated the correlation between Ultimate loads for specimens. The load bearing capability of CFSTC with that of CFST was increased from 17.5% to 18.3%. Additionally the axial shortening significantly diminished in CFSTC and its value was 10 mm as against the value of 24 mm for CFST at failure loading.

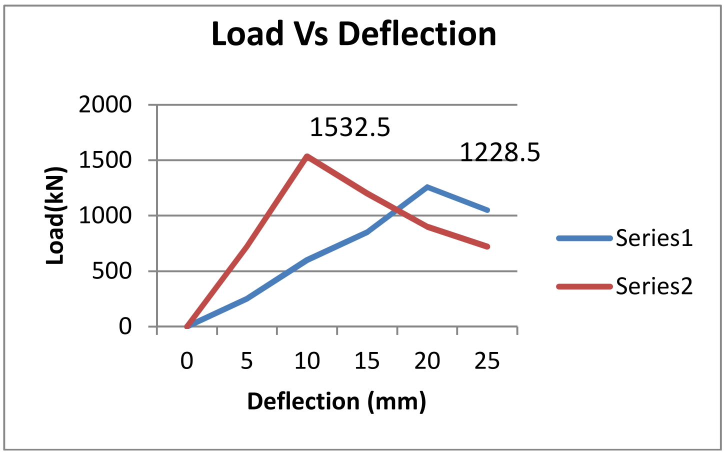

Figure .7 Comparisons of failure loads
Series1:CFST
Series2:CFSTC

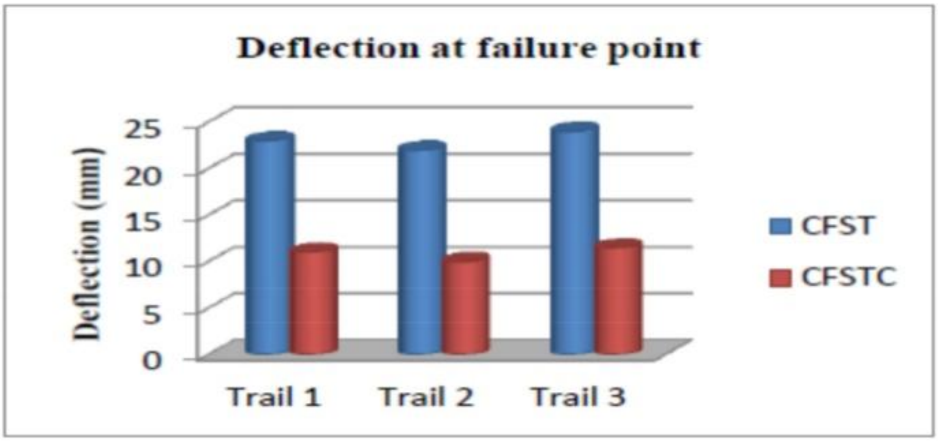

Figure.8 Deflection at Failure load

6.3 BUCKLING PATTERNS

The buckling patterns and the failure patterns seen during the test were given in Figure 10 and Figure 11. Figure 9 demonstrated the buckling behavior of all specimens. For the CFST segments without shear connectors, it could be seen from Figure 10 that nearby buckling happened at the base and top of the segment, which was due to the end impact. For the segments with shear connectors, in addition to end impact, the shear connectors prevented the strain development along the height of the specimen which in turns restricted the outward buckling as shown in Figure 11

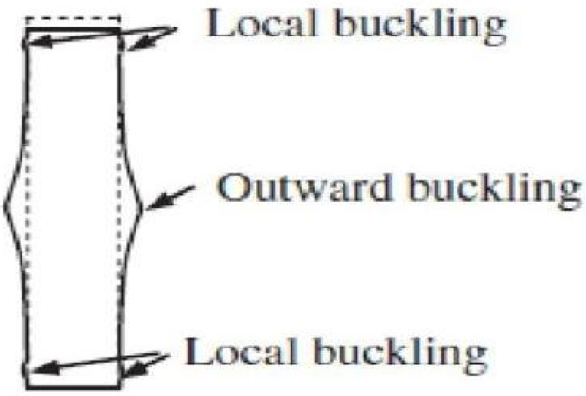

Figure.9 Failure Pattern

Figure .10 CFST

Figure .11 CFSTC

7. CONCLUSIONS

On the basis of the results,

- By the addition of chemical admixture which is High Range Water Reducing Admixture (HRWRA) resulted in increase in workability of the mixes which showed better compressive strength.
- There were significant enhancements in the physical performance of CFSTC (columns with shear connectors) in reference to ultimate load bearing capacity, stiffness and ductility.
- The consequences from push out tests specified that bond strength of CFSTC (with shear connector) specimens were found to be superior to the CFSTs specimens. It was obtained from results that the bonding capability enhanced to 17%.
- From load versus deflection curve, the proportional increase in load carrying capability of CFSTC (with shear connectors) increased in the range of 17.3% to 18.25S%., when compared with CFST columns.
- Though, there was no drastic improvement in load carrying capacity of the axial loaded CFSTC columns, it offers more ductility than the CFST columns.
- Hence, CFSTC (with shear connectors) can be used in seismic areas for better physical behavior.

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