STRUCTURAL PERFORMANCE OF HIGH STRENGTH LIGHT WEIGHT CONCRETE FILLED STEEL TUBE COLUMN UNDER AXIAL LOADING

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ABSTRACT

High rise structures constructed with the lightweight high strength concrete filled steel tube (LWCFST) column has many advantages as compared to the regular steel or the reinforced concrete column. One of the main advantages of concrete filled steel tube (CFT) is the interaction between the steel tube and concrete, since the local buckling of the steel tube is delayed by the restraint of the concrete, and the strength of concrete is increased by the confining effect of the steel tube. This paper comprises the structural behavior of lightweight CFST column under axial loading and research findings about modulus of elasticity, bond stress capacity, comparison of theoretical and experimental load carrying capacity of CFST, and fire effect. Steel tubes are compared for different lengths, cross sections and constant thickness. By using Sintagg Light weight aggregate, high strength structural light weight concrete of M30 grade was developed which reduced dead load of structural column up to 25.30% as compared to normal concrete. Analytical values for squash load were calculated and found much less than experimental values showed the reserve strength in the columns, designed as per code specified formulae as per codes (AIJ, ASCI, EC-4 and BS-5).

Keywords: High strength light weight concrete (LWC), Sintagg, Concrete filled steel tube column (CFST), Modulus of Elasticity, Confining Effect.

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1. INTRODUCTION
The concrete filled steel tube (CFT) strut system is much advantageous as compare to the common steel or reinforced concrete system. The steel tube in a Concrete Filled Tubular Strut (CFT) perform a role of longitudinal and transverse reinforcements, hence subjected to biaxial stresses. The advantages of CFT over other composite members are that the steel tube provides formwork for the concrete as well as the filled-in concrete prevents local buckling of the steel tube wall and hence concrete spalling can be avoided. The confinement effect plays a big role on the load carrying capacity of CFT. The conventional methods of design and construction causes to increase in dead load of structural members, less stiffness and span restrictions. The purpose of this study was to study the structural behavior (Stress-strain graph and buckling behavior) of composite strut and to compare the load carrying capacity of lightweight aggregate concrete filled steel tubular struts with that of normal weight aggregate concrete filled steel tubular struts. In order to expose the performance of CFT struts, specimens were designed for axial compression loading. The high strength Light weight concrete M30 grade was designed as per Indian code specifications (IS: 10262-2009) and used as core material in the steel tubes. The ultimate strength (squat load) of struts were calculated by using various codes and compared with experimental results.

2. MATERIALS
Structural LWC has an in-place density (unit weight) on the order of 1440 to 1840 kg/m³ compared to normal weight concrete a density in the range of 2240 to 2400 kg/m³. As per IS recommendations the concrete strength should be greater than 17.0 MPa for structural applications. The concrete mixture is made with a lightweight Sintagg coarse aggregate. In some cases a portion or the entire fine aggregates may be a lightweight product. Lightweight aggregates used in structural lightweight concrete are typically expanded shale, clay or slate materials that have been fired in a rotary kiln to develop a porous structure. Other products such as air-cooled blast furnace slag are also used. Sintagg is made from the sintering process of fly ash.

Sintagg is formed into small round pellets, which are then processed to create very hard aggregates with a honeycombed internal spongy structure (figure 1). It is Marketed By: G.B.C. India, Ahmadabad, Gujarat, India. Typical physical properties of Sintagg are tabulated in table 1. The high strength structural light weight concrete is designed by IS: 10262-2009 for M30 grade concrete. The mix design proportion is depicted in table 2.

<table>
<thead>
<tr>
<th>Aggregate Size (mm)</th>
<th>Bulk Density</th>
<th>Bulk Porosity</th>
<th>Aggregate Strength</th>
<th>Water Absorption</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-16 @800 kg/m³</td>
<td>35-40%</td>
<td>&gt; 4.0 MPa</td>
<td>&lt; 16 %</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material</th>
<th>Cement</th>
<th>Water L.W.A.</th>
<th>F. A.</th>
<th>Superplasticizer</th>
<th>Microsilica</th>
<th>W/C ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity (kg/m³)</td>
<td>442</td>
<td>154</td>
<td>138</td>
<td>552</td>
<td>61</td>
<td>4.862</td>
</tr>
</tbody>
</table>

The CFST column specimens were prepared by using Mild Steel tubes and M30 grade LWC concrete used to fill steel tubes. Light weight concrete consist the materials as, Nusil-50 Micro Silica used with 10% by weight of cementitious materials. It is collected from Sai Durga Enterprises, Banglore, Karnataka, India. BASF Super plasticizer was used. Cement
and sand is purchased from local places. Ultra Tech 53G- PPC Cement with natural River sand of zone II was used to prepare concrete.

3. EXPERIMENTAL PROGRAM

3.1. Casting and Testing of CFST Column Specimens
The CFST column specimens are prepared by filling the high strength light weight concrete inside the steel tube. The Circular, Rectangular and square shaped steel tubes are selected to prepare the specimens. As per IS code provisions of short column the lengths of column are decided between 400mm to 800mm varying in thickness from 2mm, 3mm, & 4mm. So, length and thickness parameters are vary here to study the behavior of CFT column.

Total 40 nos. of specimens are prepared with LWCFST. The deposits of grease and oil, if any, were cleaned away. Steel end plates were then welded at the section extremities. The centering and perpendicularity of the end plates were given special attention to ensure a high degree of accuracy. Two end plates were designed to strengthen the connections between the top plate or the bottom plate and the specimen. Four circular holes of 20 mm in diameter located at the corner of the plate to provide proper connection while testing of specimens. The concrete was mixed in a traditionally by hand mixing. The concrete was filled in layers and was vibrated by vibrator. The specimens were put under dry curing method by covering concrete surfaces with Hessian or canvas or Gunny Bags.

![Specimens](image)

**Figure 1** Specimens

3.2. Experimental Set up
All specimens were tested under Universal Testing Machine (UTM-100T) with digital recording facility by an incremental monotonic loading in a 1000 KN capacity at the loading rate of 50 KN/Min. to observe buckling behavior and failure pattern. All specimens were prepared and tested under the applied load with a high degree of accuracy universal testing machine to make sure the load application to the required positions as shown in Figure no.2. All readings of specimens are recorded by digitally and related graphs are generated by software of UTM. While testing, Dial gauges are connected to all specimens at 1/2 L and 1/3 L of each specimen to observe the transverse deflections.
3.3. Study of Design Codes

The load carrying capacity of composite column (CFT) member is the strength of the cross section, which is usually expressed in terms of the squash load and the ultimate moment of resistance. Indian Standard code specification is not available yet, for the design of concrete filled steel column. Several design methods for concrete-filled tubular columns have been developed in different countries and some are under development. The guidelines for design method of concrete-filled columns was presented in codes listed as below

- UK-Bridge Code (BS-5400-5)
- Load & Resistance Factor Design Specification (AISC-LRFD)
- Euro code (EC4)
- Architectural institute of Japan (AIJ)

3.3.1. Comparison of analytical loads carried by short CFST column using various codes stated above

Following figures are showing the comparison of squash load for Circular, square and rectangular CFT by codes.

![Figure 2: Testing Setup under Universal Testing Machine](image)

![Figure 3: Graph (a)-circular column squash](image)

![Figure 4: Graph (b)-square column squash load](image)
4. RESULT & DISCUSSION

4.1. Load Carrying Capacity vs. Slenderness Ratio behavior of LWHCFST

The load Vs. slenderness ratio of Circular, Rectangular & Square CFT columns specimens are plotted to study the effect of change in slenderness ratio on LCC & failure behavior of CFT. Following figure shows the graphical representation of load vs. slenderness ratio.
Structural Performance of High Strength Light Weight Concrete Filled Steel Tube Column Under Axial Loading

From the above figure, for circular column, as slenderness ratio increases, L.C.C decreases from length 400 mm to 800mm but it was slightly increases for 600mm for all shapes due to crushing of concrete followed by confining effect of concrete core inside the tube.

4.2. Failure Modes of LWHCFST

Nearly all columns failed due to local buckling and concrete crushing. Local buckling was observed after the elastic stage follow to concrete crushing. The typical crushing failure mode was observed where the steel wall was short of out by the concrete core, which shows confinement effect.

Generally, four different types of failure modes were identified from experimental tests of CFST columns under axial compression,

- Local buckling
- Plastic hinge
- Shear
- Global buckling

Local buckling failure often occurs at multiple locations along the column length. Figure 4 shows how a plastic hinge can form when several local buckles are concentrated at one location along the column length, causing the column to bend. Alternatively, shear failure can occur where the concrete core has shifted along a slanted plane. Finally, global buckling is shown, where the column bends at one location often near mid-height.

Circular Columns

In the initial stages loading of the circular CFT columns are subjected to axial load while Poisson ratio for concrete is lower than that for steel. Therefore, separation between the steel tube wall and concrete core takes place. The behavior of circular columns is much superior as compared to square ones (Figure 9 & 10). At failure, ring shaped buckles developed outwards mostly near the top or bottom ends of the column.

Square Column

![Figure 9 (a) Failure modes for circular & square columns](image1)
![Figure 10 (b) Failure modes for circular & square columns](image2)
In the case of square columns, it is necessary to take into consideration a capacity reduction due to local buckling of the steel tube wall of the column with large $B/t$ ratio rather than the confinement effect of the steel tube. Local buckling occurred equally on every face for the square tube. Also, the compressive strength decreases as the length of square columns increases.

3. RECTANGULAR COLUMN

Rectangular and square tubes showed quite similar local buckling behavior. Most of the local wall buckling of the circular cross section was due to a radial expansion of the tube. The square and rectangular tubes, however, showed clear signs of wall bulging. For the rectangular CFT, local buckling was more extensive for the broad face than for the narrow face. In general, tubes with large $D/t$ ratios had more local wall buckling, with higher apparent distortions, compared to the sections with small $D/t$ ratios. This behavior accounted for the differences observed in the strain-hardening and strain-softening characteristics of the steel tube shapes.

![Figure 11 Failure modes for rectangular columns](image1)

![Figure 12 Failure mode for circular column on ABAQUS](image2)

4.3. Stress Strain behavior of CFST Specimens

The graphs for axial Stress Vs axial Strains are plotted for Circular, Rectangular and square specimens varying in thickness and lengths. Each graph shows the stress Vs strain behaviour for same cross section of column with same thickness and varying in length, which are
comparatively studied. If stress strain graphs for all circular, rectangular & square shapes are observed comparatively, all specimens shows same or unique pattern of stress strain curve. All columns behaved in almost similar way with yielding strain observed. For circular columns, yielding strain ranges between 0.022 and 0.025 and stress in steel around 55 MPa - 75 MPa at failure. Similarly for square columns yielding strain ranges between 0.022 and 0.025 and stress in steel around 85 MPa - 122 MPa at failure. As thickness of specimen increase the stress increases and as length increases stress decreased.

From the graphs it is seen that as slenderness ratio decreases the axial stress & strain capacity increases in circular, rectangular and square sections. All specimens shows the stages in stress strain curve as below, figure
A. Proportionality limit
B. Elastic limit
C. Yield point
D. Ultimate stress point
4.4. Comparison of LCC of CFT Column Filled with LWC and Normal Concrete

The load carrying capacity of LWCFST specimens is found to be very close to normal concrete filled specimens. For circular LWCFST column of 2mm, 3mm, & 4mm percentage decrement of load carrying capacity compared with normal concrete is 10.34%, 3.02%, & 9.03% respectively. Similarly for rectangular specimens it was 12.60%, 3.31& 3.34% respectively and square columns of 3mm & 4mm it was 7.56% & 10.42% respectively.

Circular 3mm thick & 600 mm length specimen shows LCC 14% more than same size of normal concrete specimen. Similarly rectangular 2mm thick & 700 mm length specimen shows LCC 23% more than same size of normal concrete specimen.

4.5. Calculation of Modulus of Elasticity of CFT Columns

When thickness of specimen remains constants from the above stress strain graphs, the Modulus of Elasticity is calculated. For the calculation of Modulus of Elasticity (Ec), in compression, the straight portion of stress strain graph was considered to obtain the ordinates. From these ordinates, slope of the stress strain graph was calculated which is also the Modulus of Elasticity. Mean = 8977, Variance = Σd²/24 = 10957204, Standard deviation = √Variance = 3310.167, Hence Modulus of Elasticity (Ec) = 8977 ± 3310.167 N/mm²

5. CONCLUSION

Conclusion is presented regarding the experimentally evaluated CFST columns about the load carrying capacity with comparison of analytical and experimental results.

The Following Concluding Remarks Can Be Made From The Results Of This Investigation:

- By using sintagg light weight aggregate, high strength structural light weight concrete of m30 grade is developed which reduces dead load of structural members up to 25.30% as compared to normal concrete.
- The L.C.C. of CFST specimen is increase as d/t ratio decrease when slenderness ratio i.e. Le/d and d is kept constant. As slenderness ratio increases, L.C.C decreases from length 400mm to 800mm but it slightly increases for 600mm.
- The load carrying capacity obtained from analytical results of four codes show that the squash load is less in BS-5, AIJ codes and it is maximum for EC-4 and AISC/LRFD codes. All analytical values are much less than an experimental value, which shows the reserve strength of 70% in the columns, designed as per code specified formula. For circular columns, yielding strain ranges between 0.022 and 0.025 and stress in steel around 55 Mpa -75 Mpa at failure. Similarly for square columns yielding strain ranges between 0.017 and 0.02 and stress in steel around 85 mpa -122 mpa at failure. As thickness of specimen increase the stress increases and as length increases stress decreased.
- The load carrying capacity of LWCFST specimen’s is found to be very close to normal concrete filled specimens. For circular LWCFST column of 2mm, 3mm, & 4mm percentage decrement of load carrying capacity compared with normal concrete is 10.34%, 3.02%, & 9.03% respectively. Similarly for rectangular specimens it was 12.60%, 3.31& 3.34% respectively and square columns of 3mm & 4mm it was 7.56% & 10.42% respectively. Circular 3mm thick & 600 mm length specimen shows LCC 14% more than same size of normal concrete specimen. Similarly rectangular 2mm thick & 700 mm length specimen shows LCC 23% more than same size of normal concrete specimen.
- From stress-strain relationship it is found that the range of modulus of elasticity in compression for CFST short column is 8977 ± 3310 N/mm²
The buckling failure pattern for square CFST column it was observed that local buckling takes place, while for circular and rectangular CFST columns plastic buckling takes place and same result is observed for the CFST columns exposed to temperature variation.

The axial strengths found in ABAQUS are compared with experimental results; it is observed that for experimental results are 10.47% more than the axial strengths estimated by ABAQUS.

**APPENDIX: NOTATION**
- CFT: concrete filled steel
- LCC: load carrying capacity
- LWHCFST: light weight high strength concrete filled steel tube
- \( \frac{d}{t} \): ratio of depth of column to thickness of tube
- \( \frac{le}{l} \): effective length of column to total length of column
- \( d \): depth of column
- \( D \): steel tube outside dimension
- \( E_c \): elastic modulus for column

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