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Structural Behavior of High Strength Light Weight Concrete Filled Steel Tube Column

Mr. Pramod B. Salgar[1], Dr. P. S. Patil[2]

Research Scholar, Civil Engineering Department, R.I.T. Sakharale, Maharashtra, India.

Ph.D., Professor, Civil Engineering Department, R.I.T. Sakharale, Maharashtra, India.

Abstract: High rise structures constructed with the lightweight high strength concrete filled steel tube (LWCFST) column has many advantages compared with the ordinary steel or the reinforced concrete column. One of the main advantages is the interaction between the steel tube and concrete: 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 is developed which reduces dead load of structural column up to 25.30% as compared to normal concrete. All analytical values are much less than an experimental value, which shows the reserve strength in the columns, designed as per code specified formula.

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

I. INTRODUCTION

The concrete filled steel tube (CFST) column system has many advantages compared with the ordinary steel or the reinforced concrete system. One of the main advantages is the interaction between the steel tube and concrete: 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. The steel tube in a Concrete Filled Tubular Column (CFST) acts as both longitudinal and lateral reinforcement, and is thus subjected to biaxial stresses. The advantages of CFST 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 is also playing a big role on the load carrying capacity of CFST. With all above advantages light weight concrete reduces the dead weight of column will affect on structural performance of column. The conventional methods of design and construction cause to increase in dead load of structural members, less stiffness and span restrictions. Also, formwork placement and dismantling are tedious work consumes time which leads to delay in work and increase duration of project which in turn directly harms cost of project. Also, conventional R.C.C. structures are very prone to seismic damages. In order to expose the performance of CFST columns, specimens will be designed for axial compression loading. The Concrete that will be considered is high strength Light weight concrete for infill in steel tubes. Based on these factors, failure patterns & influence of Light weight concrete slenderness ratio to Ultimate load ratio, Bond stress & Modulus of elasticity are analysed.

II. 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). These hard pellets can then be used as a superior, consistent, lightweight aggregate which is up to 50% lighter than natural aggregate. 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.

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Table 1 Typical Physical Characteristics of Sintagg:

Aggregate Size (mm)	Bulk Density	Bulk Porosity	Aggregate Strength	Water Absorption
8-16	@800 kg/m^3	35-40%	> 4.0 MPa	< 16 %

Table 2 Mix design proportion of M30 Light weight concrete

Material	Cement	Water	L.W.A.		F.A.	Super-plasticizer	Micro silica	W/C ratio
			(4-8)mm	(8-12)mm				
Quantity (kg/m^3)	442	154.38	138	552	617	4.862	44.2	0.35

The CFST column specimens were prepared by using Mild Steel tubes and M30 grade LWC concrete used to fill steel tubes. Light weight concrete consists the materials as, Nusil-50 Micro Silica used with 10% by weight of cementitious materials. It is collected from Sai Durga Enterprises, Bangalore, 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.

III. 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 varied here to study the behavior of CFT column.

Total 40 nos. of specimens are prepared with LWCFST. The ends of the steel tubes were cut and machined to the required length. The insides of the tubes were wire brushed to remove any rust and loose debris present. 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. A concrete placement bucket and a funnel were used to deposit the mix in the steel column. 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.

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 placed under the applied load with a high degree of accuracy to ensure 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.

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Figure 1-Testing Setup under Universal Testing Machine

3.3 Study of Design Codes

In calculating the capacity of composite column member, the strength of the cross section, which is usually expressed in terms of the squash load and the ultimate moment of resistance, is a basic requirement. There is no Indian Standard specification available 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 design methods or recommendations of concrete-filled columns will be presented for codes listed as below

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

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

Table 3- Analytical and Experimental L.C.C. of CFST column having 400mm length

Sr No	Shape	Section properties		Material properties (N/mm^2)		Analytical (KN)				Experimental (KN)
		d/t	Le/D	F_c	F_y	BS-5	EC-4	AISC/LRFD	AIJ	
1	Circular	40	3.25	30	310	192.89	222.83	236.18	219.35	379.8
2	Circular	26.67	3.25	30	310	253.25	281.64	304.32	247.81	527
3	Circular	20	3.25	30	310	312	338.87	370.61	304.95	619.35
4	Square	26.67	3.25	30	310	322.45	358.59	377.38	263.97	568.9
5	Square	20	3.25	30	310	397.25	431.47	462.5	320.42	683.15
6	Rectangle	20	6.5	30	310	161.74	179.79	186.47	132.37	250.8
7	Rectangle	13.33	6.5	30	310	218.09	234.7	248.99	174.9	360.8
8	Rectangle	10	6.5	30	310	272.4	287.61	308.88	215.89	398.55

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Table 4- Analytical and Experimental L.C.C. of CFST column having 500mm length

Sr No	Shape	Section properties		Material properties (N/mm^2)		Analytical (KN)				Experimental (KN)
		d/t	Le/D	F_c	F_y	BS-5	EC-4	AISC/LRFD	AIJ	
1	Circular	40	4.06	30	310	192.89	222.83	235.09	185.69	293.8
2	Circular	26.67	4.06	30	310	253.25	281.64	303.00	242.75	557.45
3	Circular	20	4.06	30	310	312	338.87	369.03	298.29	587.65
4	Square	26.67	4.06	30	310	322.45	358.59	376.17	263.97	528.9
5	Square	20	4.06	30	310	397.25	431.47	461.05	320.42	610.5
6	rectangle	20	8.12	30	310	161.74	179.79	184.32	132.37	173.3
7	rectangle	13.33	8.12	30	310	218.09	234.7	245.78	174.9	331.3
8	rectangle	10	8.12	30	310	272.4	287.61	304.44	215.89	360.8

Table 5- Analytical and Experimental L.C.C. of CFST column having 600mm length

Sr No	Shape	Section properties		Material properties (N/mm^2)		Analytical (KN)				Experimental (KN)
		d/t	Le/D	F_c	F_y	BS-5	EC-4	AISC/LRFD	AIJ	
1	Circular	40	4.87	30	310	192.89	222.83	233.78	182.28	360
2	Circular	26.67	4.87	30	310	253.25	281.64	301.40	237.70	508.4
3	Circular	20	4.87	30	310	312	338.87	367.13	291.63	608.65
4	Square	26.67	4.87	30	310	322.45	358.59	374.71	263.97	570.75
5	Square	20	4.87	30	310	397.25	431.47	459.29	320.42	734.39
6	rectangle	20	9.75	30	310	161.74	179.79	181.73	132.37	181
7	rectangle	13.33	9.75	30	310	218.09	234.7	241.91	174.9	340.7
8	rectangle	10	9.75	30	310	272.4	287.61	299.11	215.89	372.8

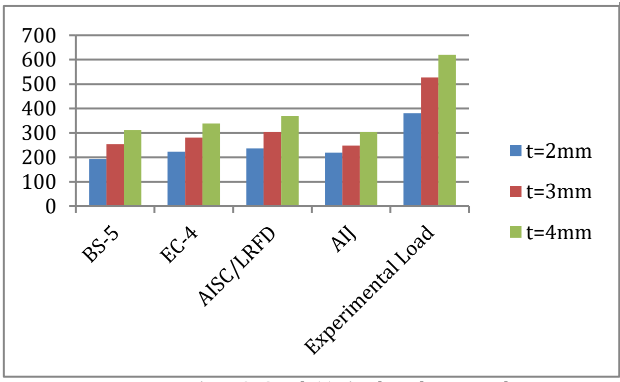

Figure 2- Graph (a)-circular column squash

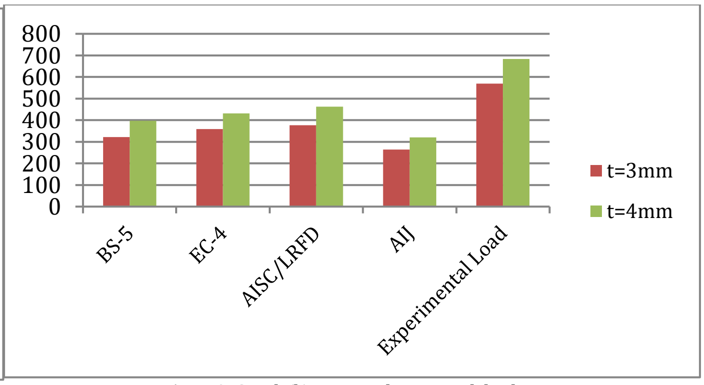

Figure 6- Graph (b)-square column squash load

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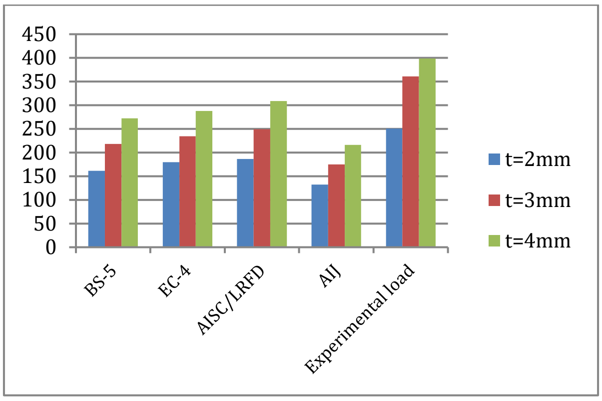
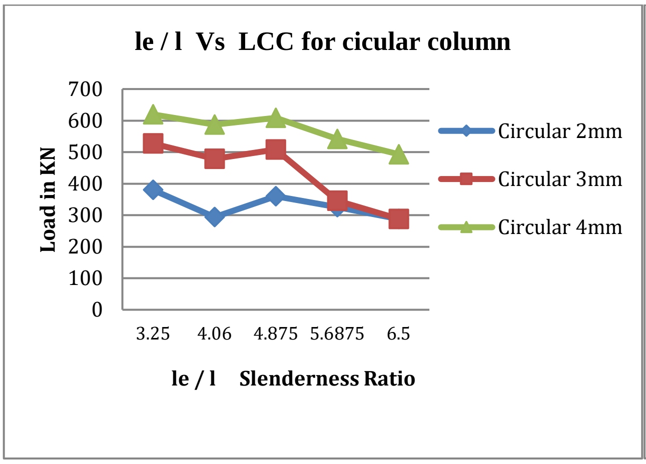


Figure 6- Graph (c)-rectangular column squash load

IV. 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.



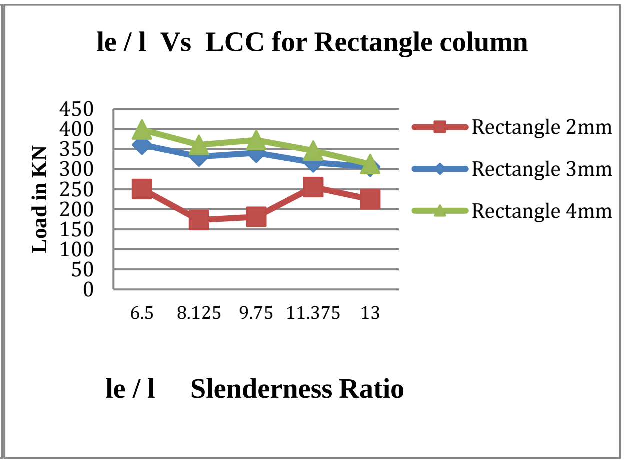


Fig. 4.1 le / l Vs LCC for Circular column **Fig. 4.2 le / l Vs LCC for Rectangle column**

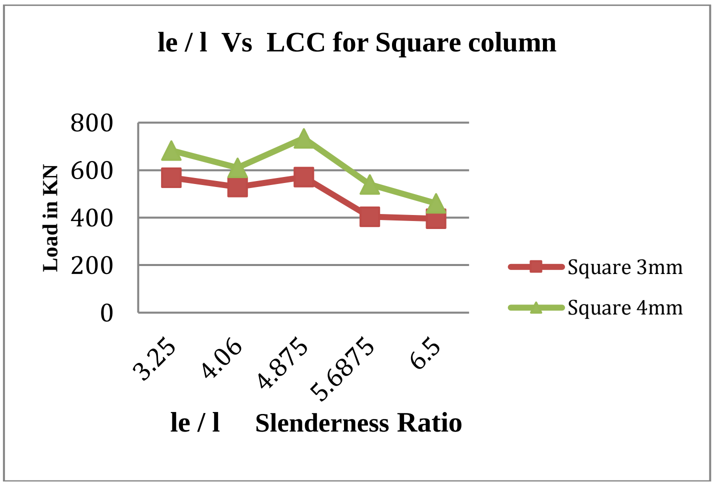


Fig. 4.3 le / l Vs LCC for Square column

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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:

Almost all columns failed due to local buckling and concrete crushing. Local buckling took place after the elastic range, and after this concrete crushing followed. The failure mode of almost all columns at the bottom or the top was a typical crushing failure mode where the steel wall was pushed out by the concrete core, which in turn was confined by the steel. When the steel was removed from the specimen after failure, the concrete was found to have taken the shape of the deformed steel tube, which illustrates the composite action of the section.

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

a. Local buckling
b. Plastic hinge
c. Shear
d. 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.

1. 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. As the load increases, the longitudinal strain reaches a certain critical strain. The lateral deformation strength and the nominal squash load are enhanced by the confining effect on concrete, and this enhancement depends upon the tube strength. Figure 4.1 indicate the behavior of circular columns is much better as compared to square ones for filled series. At failure, ring shaped buckles developed outwards mostly near the top or bottom ends of the column.

2. Square column

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 had fairly similar local buckling behavior. Clearly, 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.

Fig.4.1: Failure modes for circular & square columns

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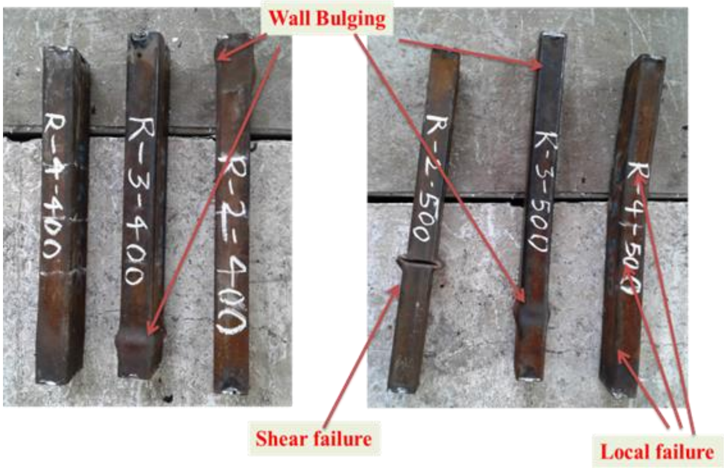

Fig.4.2: Failure modes for rectangular columns

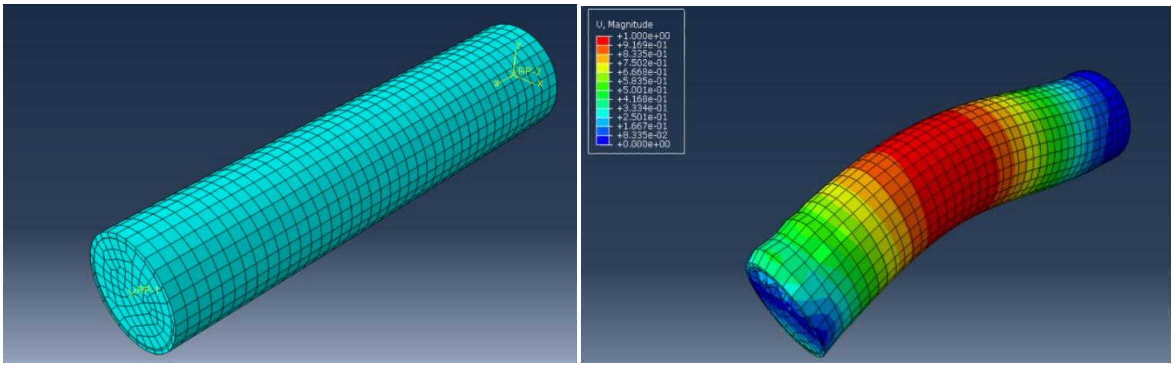

Fig.4.3: Failure mode for circular column on ABAQUS

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

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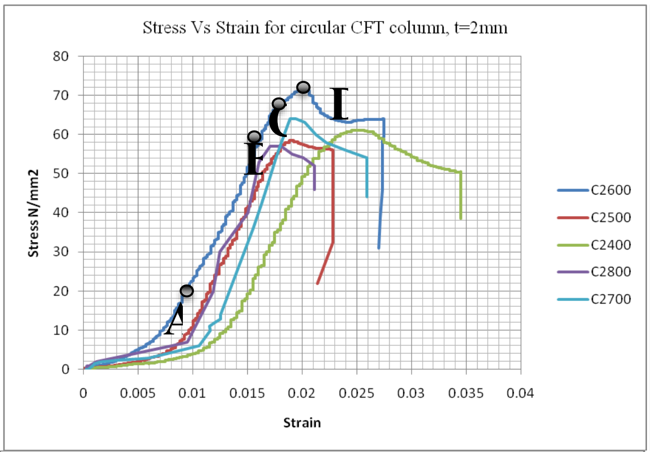

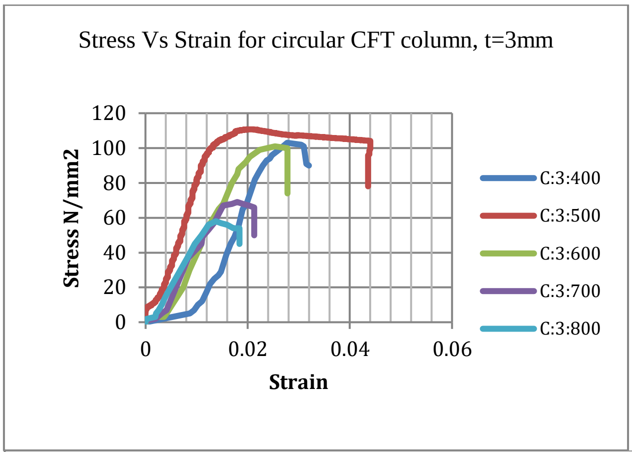

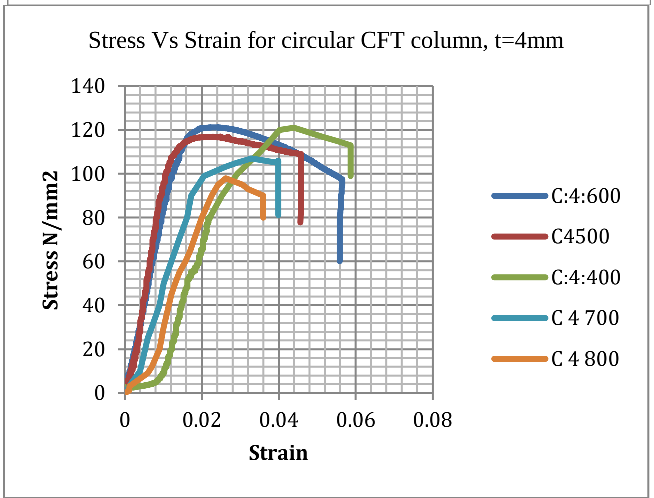

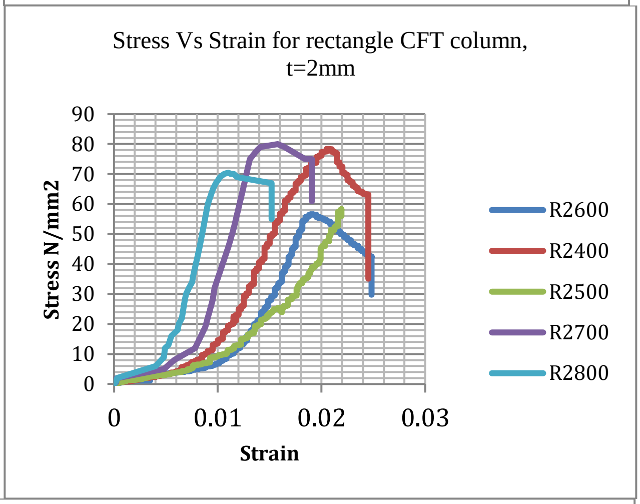

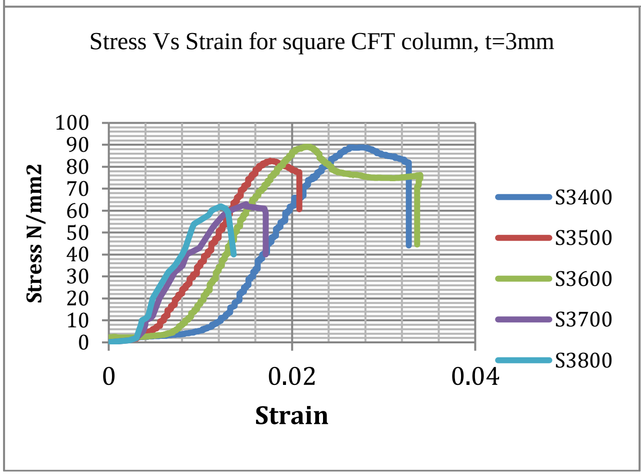

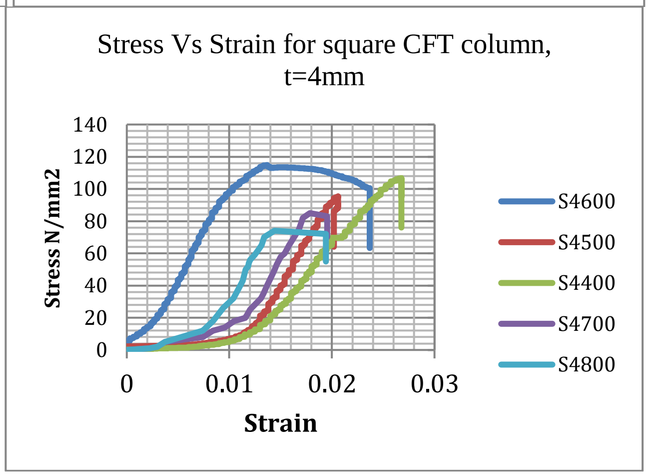

4.4 Comparison of LCC of CFT column filled with LWC and Normal concrete:

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.

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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 = $\Sigma d^2/24$ = 10957204, Standard deviation = $\sqrt{\text{Variance}}$ = 3310.167, Hence Modulus of Elasticity (Ec) = 8977 ± 3310.167 N/mm^2

V. 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:

1. 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.
2. 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.
3. 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.
4. 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.
5. From stress-strain relationship it is found that the range of modulus of elasticity in compression for CFST short column is 8977 ± 3310 N/mm^2
6. 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.
7. The axial strengths found in ABAQUS are compared with experimental results; it is observed that for experimental results are10.47% more than the axial strengths estimated by ABAQUS.

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