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Structural Behavior of Lightweight Concrete Filled Steel Tube Column of Different Cross Section Under Axial Compression

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Abstract - Highrise buildings constructed with the lightweight concrete filled steel tube (LWCFST) column has many advantages as compared to the steel column or the reinforced concrete column. The interaction between the steel tube and concrete is one of the primary benefits of concrete filled steel tube (CFT), as the confining effect of the steel tube increases the strength of the concrete and delays the local buckling of the steel tube due to the concrete's constraint. This study comprises the structural behavior of lightweight CFST column of different cross section under axial loading and research findings about stress strain relationship, and comparison of experimental load carrying capacity with analytical results using ANSYS software. In this study Concrete-filled double-skin stiffened steel tubular (CFDST) Columns considered as a new type of Concrete Filled Steel Tubular (CFST) Columns. It is made up of an outer and inner steel tube and an annulus filled with lightweight concrete between the skins. Compared to CFST, CFDST has numerous benefits, including greater damping properties, section modulus, stability, and weight reduction. Sintagg Lightweight aggregate was used to create high strength structural light weight concrete of M40 grade, which decreased the structural column's dead load by up to 29.94 percent when compared to normal concrete. The results and observation from the test reveals significant difference between CFDST and CFST, showcasing enhanced strength parameters. This study emphasizes the potential benefits of using double skin steel tube column in high rise buildings and it is an effective approach to enhance the strength parameters of columns.

Index Terms - Concrete filled steel tube column (CFST), Double skin steel tube (CFDST), Light weight concrete (LWC), Sintagg

I. INTRODUCTION

The advantages of concrete and steel are combined in concrete filled steel tubular (CFST) members. They are frequently utilized as beams in low-rise industrial buildings where a strong and effective structural system is needed, as well as columns and beam-columns in high-rise and multistory buildings. These kinds of structural systems have several unique benefits for the order of construction as well as the structural performance. When it comes to preventing axial compression, the concrete core contributes more. Being stiffer than non-composite steel columns is a key characteristic of CFST columns. Because steel members are very ductile and tensile strong, they are utilized to resist construction loads and to erect buildings. The steel casing will strengthen the column considerably in thin columns where buckling is likely to occur. The steel casing limits the core and the filled concrete prevents localised buckling of the shell when the concrete-filled steel tubular columns are used in appropriate circumstances. But the low specific gravity of lightweight concrete, which results in lighter structures, and its thermal conductivity appear to be strong arguments in favour of employing lightweight concrete in composite construction. Because lightweight concrete has so many benefits over traditional concrete, its application has increased recently. A type of concrete known as lightweight concrete is one that has an expanding agent added to it, which raises the mixture's volume while decreasing its dead weight.

With a dry density ranging from 300 kg/m3 to 1840 kg/m3, it is less dense than traditional concrete. Lightweight concrete excels in two areas: low density and low heat conductivity. Longer spans, fewer piers, and longer lifespans for bridge structures are made possible by lightweight concrete (LWC), which is lighter and more durable. By lowering self weight and facilitating the construction of bigger precast pieces, structural grade light weight concrete is used. Concrete has been the subject of an experimental investigation in which another light-weight aggregate has been used in part place of the traditional coarse aggregate. It has been experimentally attempted to substitute sintagg (fly ash aggregate) for the coarse aggregate.

1.1 Objective

- Research investigates the load carrying capacity of lightweight concrete filled steel tube column of different cross section under axial compression.
- The objective of this research is to determine the effective cross section with improved strength parameters of light weight concrete filled stiffened steel tube compared with concrete filled double skin steel tube.
- To analyze the LWCFST column of different cross section using ANSYS workbench.
- To determine the effective cross section with improved strength parameters.
- To compare analytical work done with the experimental result.

II. ANALYTICAL INVESTIGATION

Finite element analysis was performed on the CFST specimens using ANSYS Workbench. The deformations at each and every load were acquired from ANSYS following the specimen analysis. For every specimen, a non-linear analysis was performed. Table 6 shows the ultimate load carrying capacity of the different specimens from the analysis. The specimen is 1000 mm in length, and each model's steel tube thickness is assumed to be 2 mm.

The CFST columns were modelled using ANSYS 2021 to build a steel tube model with varying cross sections for one single skinned CFST and two double skinned CFSTs with stiffeners.

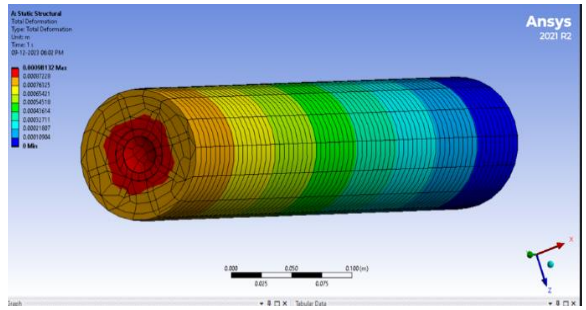


Fig 1 Axial deformation of CFST column from ANSYS

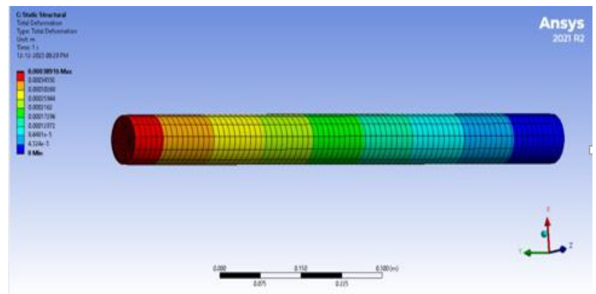


Fig 2 Stress distribution of CFST column from ANSYS

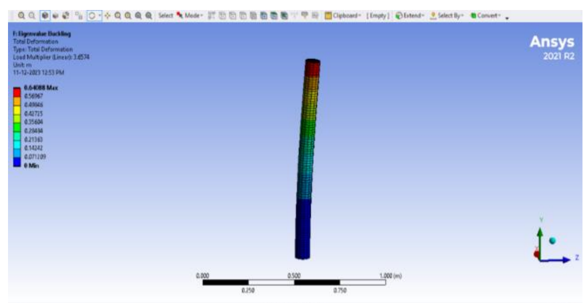


Fig 3 Buckling behavior and load carrying capacity of CFST column

The CFST specimens were analyzed using finite element analysis in ANSYS workbench. Table 2 shows that the results of the finite element analysis. After analyzing the specimens, load carrying capacity, buckling behavior, deformation, stress and strain were obtained from ANSYS. Non-linear analysis was carried out for the three specimens. Comparing the three circular column stiffened double skinned circular column (CFDST) C1 is 33.73% higher than C2 and 74% higher than C3 cross sections. In addition, compared to a single skin specimen, the weight carrying capability is increased when double skin is present with stiffeners.

Table 1 Specifications of steel tube model

Type of CFST column	D (mm)	t (mm)	L (mm)	D/t	L/D ratio	EFFECTIVE LENGTH Le (mm)	SLENDERNESS RATIO (KLe/r)
Stiffened double skinned circular column(C1)	100	2	1000	50	10	650	26
Double skinned circular column(C2)	100	2	1000	50	10	650	26
Stiffened single skinned circular column(C3)	100	2	1000	50	10	650	26

Table 2 Analytical results

Type of CFST column	Load carrying capacity P (KN)	Max Deformation (mm)	Max Principle Strain	Equivalent Stresses (MPa)
Stiffened double skinned circular column(C1)	548.61	0.9813	0.00372	4.19×10^5
Double skinned circular column(C2)	430.26	0.4047	0.0026	2.53×10^5
Stiffened single skinned circular column(C3)	310.635	0.3891	0.00034	1.09×10^5

III. EXPERIMENTAL PROGRAM

3.1 Material Properties

The following materials were used in this study to prepare the light weight concrete of grade M40. The properties of materials were determined as per IS

- Cement
- Fine Aggregate
- Sintagg (Light Weight Coarse Aggregate)
- Steel tube of different cross section

Coarse Aggregate (Sintagg Lightweight Aggregate)

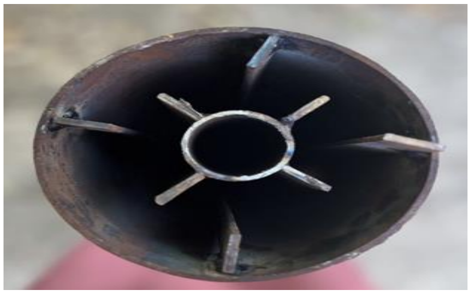
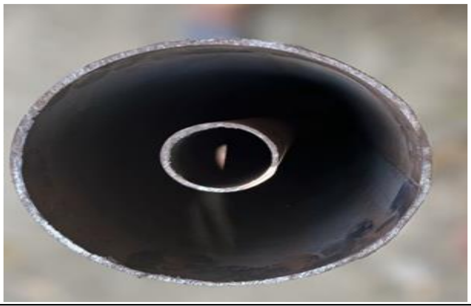
Sintagg is made from the fly ash sintering process. The Sintagg is moulded into small circular pellets and then processed into a very hard aggregate with a honeycomb- shaped internal sponge structure. These hard pellets are up to 50% lighter than natural aggregate and can be used as a superior and consistent lightweight aggregate. It is manufactured in Odisha plant and it is sold by TRIFIX infrastructure Mumbai, India.

Fig 4 Fly ash aggregate (SINTAGG)

Table 3 Physical properties of materials

SI NO	Properties	Cement	Coarse Aggregate	Fine Aggregate
1	Consistency	33%	-	
2	Initial setting time	35 min	-	
3	Final setting time	220 min	-	
4	Specific gravity	2.88	1.476	2.67
5	Water absorption	-	15%	1.63

Table 4 Specifications of steel tube

SI.NO	MODEL NAME	SPECIFICATIONS	MODEL
1	Stiffened double skinned circular column	Thickness of steel tube = 2mm Outer Steel skin D= 100 mm, H=1000mm Inner Steel skin D= 30 mm, H=1000mm Stiffener dimension =4x15x1000 mm	
2	Double skinned circular column	Thickness of steel tube =2mm Outer Steel skin D=100 mm, H=1000mm Inner Steel skin D=30mm, H=1000mm	
3	Stiffened single skinned circular column	D = 100 mm, H = 1000 mm, Thickness of steel tube = 2 mm.	

3.2 Mix Design

Table 5 Mix design of M40 grade concrete

Cement	Fine Aggregate	Lightweight Coarse Aggregate	Water	Admixture
442	648.8	727.8	154.38	5.53
1	1.47	1.65	0.35	0.0125

Mix design is the process of choosing appropriate concrete materials and figuring out how much of each is needed to produce concrete that is as durable and strong as feasible while also being as cost-effective as possible. Lightweight concrete mixes have traditionally been designed on the basis of previous work and experience. However, it has been decided to develop the high strength, light weight concrete according to IS 10262:2009 and IS 456:2000 for M40 grade are shown in table 5

3.3 Testing of Concrete Specimen

Nine cubes were cast and tested for compressive strength using a compression testing machine with a capacity of 2000 KN at 7, 14, and 28 days after curing for conventional LWA concrete cubes. Three cylinders were cast and tested at 28 days of curing using a compression testing machine with a capacity of 2000 KN. Three prisms were cast and tested at 28 days of curing using UTM testing machine with a capacity of 30 T.

a) Testing of compression strength of light weight concrete cubes

b) Testing of split tensile strength of light weight concrete cylinders

c) Testing of flexural strength of light weight concrete prism

Fig 5 Testing of Concrete specimens

3.4 Casting and Testing of CFST Columns

The circular column and stiffeners are first welded with a weld thickness of 2 mm. The column of different cross sections with same length and slenderness ratios. Three specimens were prepared and filled with light weight concrete. Sintagg was used as coarse aggregate with a max aggregate size of 8mm. For lightweight concrete a concrete mix of 1:1.45:1.67 with w/c=0.35 was used. Then M40 grade concrete is poured into the circular tube and the casted specimens are shown in Fig 6 after that the CFST columns were allowed to cure for 28 days.

CFST are tested under axial loading by using flexural testing machine loading up to 500 KN. For measuring deflection LVDT machine equipped with Prosof-14-B software was employed. This software facilitated accurate reading and monitoring of deflection during the load application process. Strain gauges are used in the steel tube for measuring the strain required in the steel tube during buckling of the column.

a) CFST columns

b) Curing of CFST column

Fig 6 Casting of CFST columns

Fig 7 Test setup for CFST column under axial loading

In compression hydraulic jack with a deformation rate of 0.01 mm/sec, the column specimens were examined under axial monotonic loading. To guarantee that the load application is in the necessary location, every specimen was prepared and positioned axially with utmost accuracy as shown in Figure 7.

3.5 Test Results

Mechanical properties of light weight concrete specimens were obtained from conducted tests. The results show that light weight concrete achieve the strength marginally equal to normal concrete. It achieves 99% of characteristic compressive strength, 80% of split tensile strength and 90% of flexural strength compared to normal concrete. While testing the specimens weight of each specimens were noted to compare the reduction in weight. The compared results were showed in chart 1.

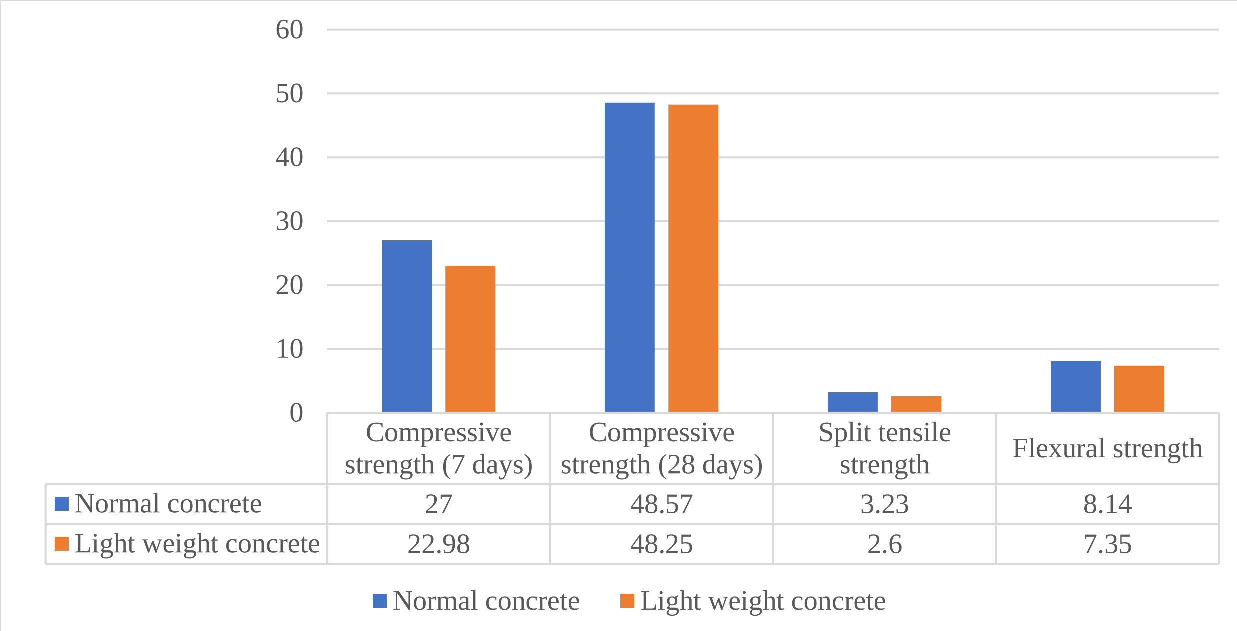


Chart 1 Comparison between Normal and Light Weight Concrete

Table 8 Comparison for weight of LWC with normal concrete

Specimen	Concrete type	Dry density (kg/m^3)	Weight (kg)	Reduction in weight (kg)	Percentage reduction	Average reduction
Cube	Light weight	1950	6.58	2.34	26.23%	19.92%
	Normal	2642.96	8.92			
Cylinder	Light weight	2146.6	11.38	2.32	16.93%	
	Normal	2584.2	13.7			
Prism	Light weight	2020	10.1	2.01	16.59%	
	Normal	2422	12.11			

CFST Column Test Under Axial Loading

From the test results, compared to cross section C2 and C3 double skinned stiffened column C1 provide better load carrying capacity and buckling behavior. The load carrying capacity of C1 is 33.73% higher than C2 and 74% higher than C3 cross sections.

Table 9 Comparison for Analytical and Experimental results

Type of CFST column	Load carrying capacity of CFST Pa (KN)	Load carrying capacity of CFST Pt (KN)
Stiffened double skinned circular column C1	548.61	572.13
Double skinned circular column C2	430.26	427.82
Stiffened single skinned circular column C3	310.635	328.96

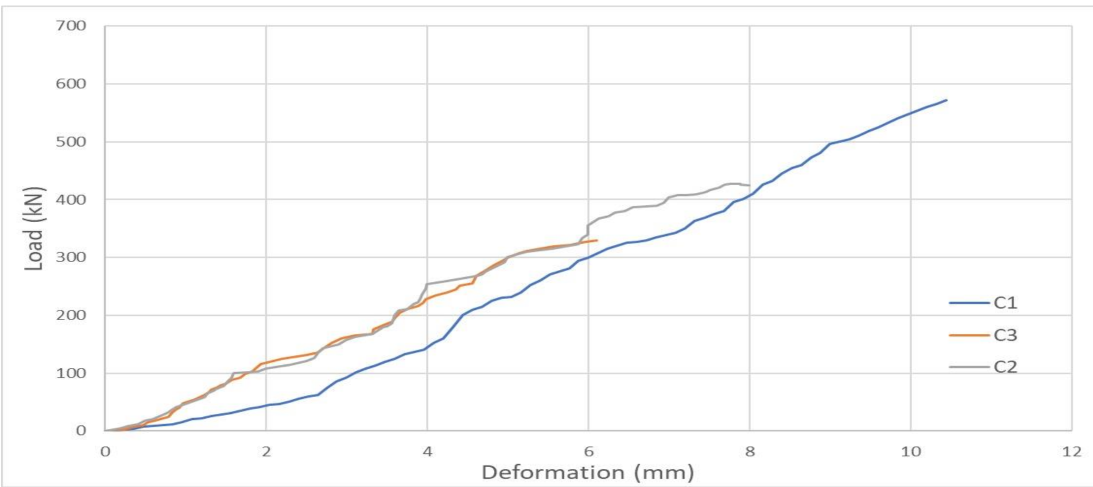


Fig 8 Load vs Deflection graph

i. C1 column provide better load carrying capacity compared to C2 & C3.

ii. Ultimate Load is approximately 33.73% higher than C2 and 73.91% higher than C3.

iii. C2: Load carrying capacity decreased by 25.22% than column C1.

iv. C3: Load carrying capacity decreased by 42.5% than column C1.

CONCLUSION

1. The light weight concrete was developed by using Sintagg aggregate having compressive strength of 40 N/mm^2 with reduction in weight by 29.24% as compared to the normal concrete.
2. Further, the normal conventional concrete cube having compressive strength of 48.57 N/mm^2 and the light weight concrete cube having strength of 48.25. This represents there is no major difference of strength by using the lightweight aggregate replaced by the normal aggregate.
3. The split tensile strength at 28 days for normal aggregate it is observed as 3.23 N/mm2 and the light weight concrete cylinder having strength of 2.6 N/mm^2 with reduction in weight by 16.93% as compared to the normal concrete.
4. The flexural strength at 28 days for normal aggregate it is observed as 8.14 N/mm^2 and the light weight aggregate prism having strength of

7.35 N/mm^2 with reduction in weight by 16.59% as compared to the normal concrete.

5. Finite element analysis in ANSYS Workbench was used to evaluate the CFST specimens. This chapter includes the findings from the finite element study. The specimens were analysed, and ANSYS was used to get the deformations at every load. The ultimate load carrying capacity of three CFST column with different cross section from the analysis is indicated in Table 6. Every model's steel tube thickness is assumed to be 2 mm, and the specimen has a length of 1000 mm.
6. The results from analytical and experimental investigation concludes that the stiffened double skinned circular column increases the load carrying capacity well as compared to column C2 and C3. The C1 column compared to C2 21.57% increased by load carrying capacity. When the C1 column compared to C3 43.38% increased by load carrying capacity. It is noticed that the C1 column gives better load carrying capacity than other two columns.

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