Experimental Study on the Strength Behaviour of Concrete-Filled Double-Skin Steel Aluminium Tube (CFDSAT) Columns with and without External Steel Rings

Merrin Roy[1], Meera C M[2]

[1]PG Student, Structural Engineering and Construction Management, Dept. of Civil Engineering, Sree Narayana Gurukulam College of Engineering, Kadayiruppu P.O, Kolenchery, Ernakulam, Kerala, India
[2]Assistant Professor, Dept. of Civil Engineering, Sree Narayana Gurukulam College of Engineering, Kadayiruppu P.O, Kolenchery, Ernakulam, Kerala, India

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Abstract - *Concrete filled steel tube columns have been adopted widely for column construction of tall buildings due to its excellent confining effect. Concrete-filled double-skin tubular (CFDST) column is one of the most efficient forms of column construction. Here the steel tubes provides both axial strength and confining pressure to enhance the strength and ductility of the in-filled concrete. Aluminum tube columns filled with concrete can effectively take advantages to provide both high strength and high stiffness. Therefore, here for the double skin two types of materials; steel and aluminium were used. Compared with confined reinforced concrete columns, CFDSAT columns had stronger and more uniform confining pressure provided to the in-filled concrete by the steel tubes, which reduces the steel congestion problem for the better concrete placing quality. However, a major shortcoming of the CFDSAT columns is the imperfect interface bonding that occurred at the elastic stage that reduces the elastic strength and stiffness of the columns. To improve this situation, it is proposed in this study to use external steel rings to restrict the dilation of outer steel tubes of CFDSAT columns. For verification, a series of uni-axial compression test was performed on some CFDSAT columns with external steel rings. From the results, it was found that the elastic strength, elastic stiffness and ductility were enhanced by installing the steel rings as external confinement.*

Key Words**: Local buckling, Load carrying capacity, Concrete-filled steel tube, Concrete-filled aluminum alloy tube, Stiffeners, Ductility, Energy absorption, Failure patterns.**

1. INTRODUCTION

Column is a major Axial load transferring member in most of the structures. According to the revised seismic codes columns should have better flexural strength in addition to the axial load carrying capacity. Its been a major concern in construction industry in previous few years to increase the column strength.

1.1 CFDST Columns

Concrete-Filled Double Skin Tubes(CFDST) is one of the latest innovations in structural engineering. Concrete filled steel tube columns have been popular for use as individual column elements. The confined concrete fill increases the axial load resistance but has little effect on the flexural resistance. For that reason, it is unlikely that these columns would be a good choice for a moment resisting frame. Filling the tube with concrete will increase the ultimate strength of the member without significant increase in cost. The main effect of concrete is that it delays the local buckling of the tube wall. But the central part of concrete in CFST columns have relatively small contribution towards bending and torsion resistance. It can be effectively replaced by another hollow steel tube with much smaller area without reducing the load carrying capacity. This structural form with the in between annulus of inner and outer steel tubes filled with concrete is called concrete filled double skin tubular columns.

Fig -1: Concrete filled double skin steel tube [4]

1.2 CFDSAT Columns

It is well known that concrete-filled steel composite columns have the advantages of high-bearing capacity and ductility, easy construction and cost saving. Aluminum tube columns filled with concrete can effectively take advantages to provide both high strength and high stiffness. There are many advantages in using aluminum alloy as a structural material, such as appearance, lightness, corrosion resistance and ease of production. However, little research has been carried out on concrete-filled aluminum tube composite columns. It uses less concrete, which creates a more sustainable environment. The tubes acts as both the longitudinal reinforcement and formwork that save the construction cost.The cavity inside the inner tube provides a possible catering of utilities like power cables, telecommunication lines, drainage pipes etc. Hence, there is a need to investigate the structural performance of concrete-filled double skin steel aluminum tube columns and the comparative study of CFDST and CFDSAT

1.3 Advantages of CFDST and CFDSAT Columns

CFST column system has many advantages compared with ordinary steel or reinforced concrete system. The main advantages are listed below.

1. Interaction between steel tube and concrete
    i. The strength of concrete is increased due to the confining effect provided from the steel tube, and the strength deterioration is not very severe, since the concrete spalling is prevented by the tube.
    ii. Drying shrinkage and creep of concrete are much smaller than ordinary reinforced concrete.
2. Cross-sectional properties
    i. The steel ratio in the CFST cross section is much larger than those in the reinforced concrete and concrete-encased steel cross section.
    ii. Lesser cross-section is required for CFDST columns when compared to ordinary reinforced column.
    iii. It uses less concrete, which creates a more sustainable environment
3. Construction efficiency
    i. Forms and reinforcing bars are omitted and concrete casting is done by tramline tube or pump-up method, which lead to savings of manpower and constructional cost and time.
    ii. Constructional site remains clean.
    iii. The cavity inside the inner tube provides a possible catering of utilities like power cables, telecommunication lines, drainage pipes etc
4. There are many advantages in using aluminum alloy as a structural material, such as
    i. appearance,
    ii. lightness,
    iii. corrosion resistance,
    iv. ease of production etc.

2. EXPERIMENTAL INVESTIGATION

2.1 Concrete Mix Design Details

A concrete mix of 25 MPa was used for this study. The concrete mix design was done as per IS 456:2000 and IS 10262:2009 inorder to achieve a 28th day compressive strength. The materials were tested for various properties needed for the mix design. Ordinary Portland Cement of grade 53 was used for the experiment. The coarse aggregates used were of size 10 mm and M-sand was used as fine aggregate. Admixture of type MASTER GLENIUM SKY 8433 produced by BASF Incorporation was added to increase the workability of concrete and to minimize the amount of water-cement ratio, for obtaining a desired slump range of 75 mm–125 mm for normal RCC work as per IS 456:2000, Cl.7.1. The final mix proportion adopted is as shown in the table -1.

Table -1: Concrete mix proportions

Grade	Mix Proportion			w/c ratio	Super-plasticizer	Compressive strength (N/mm^2)	
	Cement	Fine aggregate	Coarse aggregate			7th day	28th day
M25	1	2.52	2.24	0.42	0.20%	20.31	32.8

2.2 Details of the specimens

For the test procedure 6 types of specimens are casted. The required aluminum tubes were purchased from the local market to fabricate the column. The lengths of the specimens were 600mm and diameters were 114mm and 76mm. Each steel tube was cut into pieces by grinding machine to obtain 600mm length columns. For CFDSAT specimens the smaller diameter (76mm) aluminium tube was placed into larger diameter (114mm) steel tube and the two tubes were connected by small rod using bolted connection to avoid uneven space in-between two columns. Then the CFDSAT specimens were given external rings using welded connection in different spacings (15,12,10,6,5cm).

Further details of the specimen are given in table 2.

Table -2: Details of specimens

Label	Specimen Description
SA2	Specimen with 3 numbers of external steel rings
SA3	Specimen with 4 numbers of external steel rings
SA4	Specimen with 5 numbers of external steel rings
SA5	Specimen with 9 numbers of external steel rings
SA6	Specimen with 11 numbers of external steel rings

The different arrangement of Tubes are shown in Fig -2.

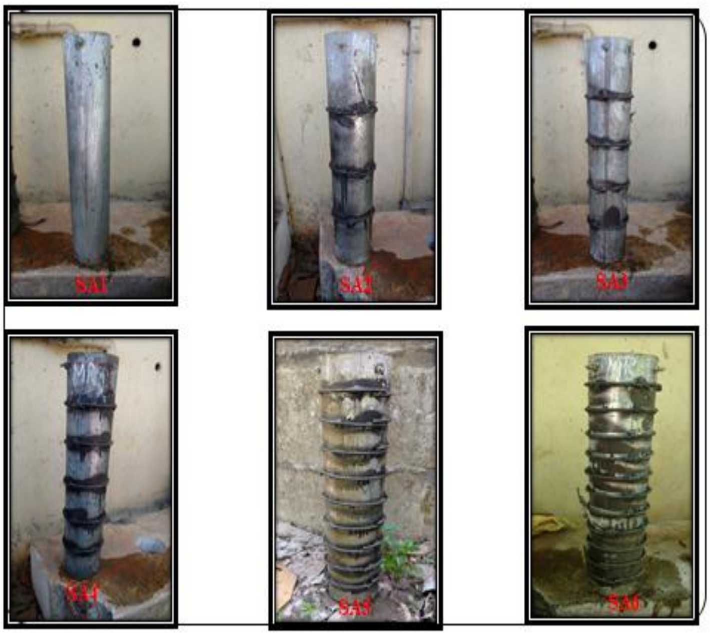

Fig -2: Different arrangement of steel rings in CFDSAT: (a) SA1 (b) SA2 (c) SA3 (d) SA4 (e) SA5 (d) SA6

2.3 Casting of CFDSAT Column Specimens

Initially, the concrete floor of the laboratory was properly cleaned to avoid the undulations which was created by the small particles during the coloumn casting. Before casting, the surface of the mould was roughly cleaned by a sand paper to remove dust and oil to get good bonding between concrete, steel and aluminium tubes. A funnel was used for pouring concrete. After pouring concrete the surface was leveled and finished. From the next day onwards curing was started. The columns were cured for 28 days in the curing tank.

2.4 Experimental setup

The CFDSAT specimens were tested in Universal Testing Machine (UTM) having load carrying capacity of 1000kN. The columns were tested under axial loading. Deflection of the column specimens were measured using a dial gauge (deflectometer) of least count 0.01 mm. Load was applied axially on the top surface of the specimens at a uniform rate till the ultimate failure occurred. For each load of 10 kN, the deflection were recorded. All specimens were subjected to load up till failure. Testing procedure for all the column specimens were same. Thus load carrying capacity of each column specimen would be calculated by applying load. The load was applied gradually up to an ultimate load and deflections were measured at various load stages. The experimental test setup of column specimens is shown in Fig -3.

Fig -4: Experimental test setup of column specimens

3. RESULTS AND DISCUSSIONS

3.1 Ultimate Load Carrying Capacity

A summary of test results for ultimate load carrying capacity and deflection of all CFDSAT column specimens are shown in table -3.

Table -3: Observed test results of CFDSAT column specimens

Sl.No.	Specimen name	Ultimate load (kN)	Ultimate axial deflection (mm)
1.	SA1	262	3.92
2.	SA2	370	5.48
3.	SA3	400	4.86
4.	SA4	440	7.8
5.	SA5	454	6.24
6.	SA6	498	10.2

The load vs deflection curve for the column specimens without external steel rings (SA1) and with external steel rings of different arrangement (SA2,SA3,SA4,SA5, SA6) were shown in chart -1.

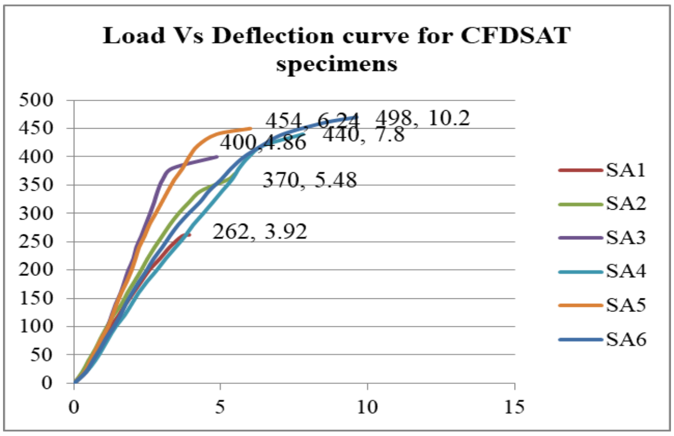

Chart -1: Load vs deflection curve for CFDSAT column specimens with and without external steel rings

The chart -2 shows Variation of Ultimate loads (kN) for CFDSAT column specimens.

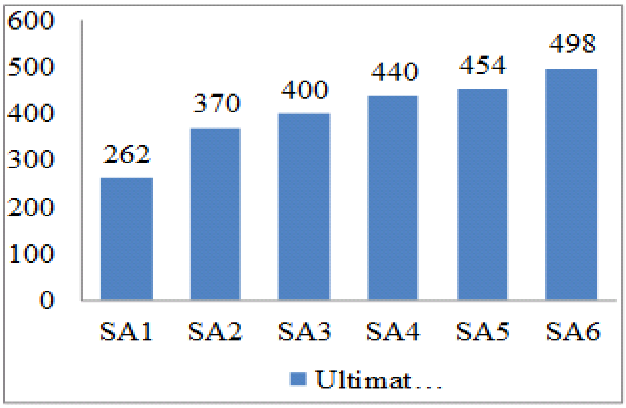

Chart -2: Variation of Ultimate loads (kN) for CFDSAT

The measured ultimate load carrying capacity of stiffened CFDSAT column specimens is larger when compared and CFDSAT column specimens without stiffeners. This increase is due to the increase in bond strength between steel or aluminium tube and in-filled concrete in stiffened CFDST or CFDSAT and due to larger effect of confining pressure provided by the stiffeners to the steel or aluminium alloy tube and the in-filled concrete. From the chart -2, we can conclude that the load carrying capacity for CFDSAT column specimens with steel rings is almost double than that for CFDSAT column specimens without external steel rings. This is because CFDSAT can delay and prevent local buckling of the steel tube , and also could effectively delay inward and outward local buckling failure of aluminium alloy members and thereby greatly enhance load carrying capacity of structural components.

The best arrangement of steel rings in CFDSAT is SA6 (11 numbers of external steel rings) with an ultimate load of 498 kN. The ultimate load carrying capacity of stiffened CFDSAT increases as the number of steel rings increases and also due to increase in bond strength between steel or aluminium tube and concrete in-fill.

3.2 Deflection ductility index (DI)

As per IS 1893 (Part-1): 2002, the ductility of a structure or its members is the capacity to undergo large inelastic deformations without significant loss of strength or stiffness. The displacement ductility index, is defined as the ratio of deflection at ultimate load to the deflection at the yield load. The Table -4 represents the deflection ductility index and ratios of CFST column specimens.

Table -4: Deflection Ductility index of CFDSAT specimens

Specimen name	Max deflection (mm)	Deflection Ductility Index (DI)
SA1	3.92	1.206
SA2	5.48	1.39
SA3	4.86	1.44
SA4	7.8	1.54
SA5	6.24	1.686
SA6	10.2	1.76

The deflection ductility indices is greater for stiffened CFDSAT due to increase in load carrying capacity, confining effect and bond strength in stiffened CFDSAT column specimens. The displacement ductility ratios of confined CFDSATs are obtained by dividing their respective deflection ductility indices with the deflection ductility index of unconfined CFDSAT specimen. From table 4, we can see that the deflection ductility ratio for CFDSAT specimen with confinement is 1.459 times greater than that of specimens without confinement. ie; there is an increase of 45.9 %.

3.3 Energy Absorption

The area under the load-deflection curve up to the ultimate load is taken as the energy absorbed by the CFDSAT column specimens with and without confinement. The chart -3 shows Variation of energy absorption (J) for CFDSAT column specimens.

Specimen name	Energy Absorbed by the specimen (J)	Energy Absorption ratio
SA1	558.74	1
SA2	643.83	1.152
SA3	677.19	1.211
SA4	696.19	1.245
SA5	700.65	1.253
SA6	734.18	1.313

Chart -3: Variation of energy absorption (J) for CFDSAT specimen

The CFDSAT columns with stiffeners has increased energy absorption compared to the CFDSAT columns without stiffeners. However, increasing both the number of steel rings in CFDSAT has improved the energy absorption due to the increased load carrying capacity of the same. From the chart -3, the energy absorption for CFDSAT column specimens with steel rings is greater than that for CFDSAT column specimens without steel rings. From the chart, we can see that, there is a 31.4% increase in energy absorption of SA1 compared to that of SA6

3.4 Failure Pattern of CFDSAT Columns

The local buckling of the steel and aluminium tube was visible in all the specimens. In most of the specimens, local buckling was observed near the top portion (one fourth height of column) of the steel and aluminium alloy tube and a slight buckling was observed near the bottom portion. The failure mode obtained for the stiffened and unstiffened CFDSAT columns are shown below.

(a) Local buckling was observed at the top portion and also 36cm from the top.

(b) Local buckling was observed at a distance 15 and 46cm of top portion portion.

(c) Local buckling was observed at top and also at a distance of 30 and 48cm from top portion

(d) Local buckling was observed at top and also at a distance of 30 and 48cm from top portion

(e) Local buckling was observed at a distance of 11cm from the top.

(f) Local buckling was observed at a distance of 38cm from the top.

Fig -5: Failure patterns observed for CFDSAT column specimens

4. CONCLUSIONS

Six CFDSAT columns with and without external external confinement were tested under uni-axial compressive load.. To improve the confining effectiveness, various spacings of external steel rings (spacing of 15cm, 12cm, 10cm, 6cm, 5cm) were investigated.
From the results, it was observed that:

- The load carrying capacity increases as the spacing of the ring reduces due to the larger confining pressure provided in the in-filled concrete. The measured load carrying capacity of ring confined CFDSAT columns is larger than that of unconfined CFDSAT counterparts.
- The ultimate load of the CFDSAT specimens with external steel rings (SS1-without rings, SS2-rings with 15cm spacing, SS3-rings with 12cm spacing, SS4-rings with 10cm spacing, SS5-rings with 6cm spacing, SS6-rings with 5cm spacing) were increased by 90.7% when compared to the SA1 (without steel rings).
- There is a 31.4% increase in energy absorption of SA1 compared to that of SA6.
- The deflection ductility ratio for CFDSAT specimen with confinement is 1.459 times greater that of specimens without confinement. ie; there is an increase of 45.9 %.

Finally, it can be conclude that CFDSAT specimen is capable of taking more load. Furthermore CFDSAT specimens provided with 5cm spacing of external rings is found to better than all other specimens.

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