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Double Skinned Hollow Composite Columns in-filled with SCC - M25, M30 and M35

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ABSTRACT

This paper describes experimental study six are Double Skinned Hollow Concrete Filled steel Tubular (DSHCFT) columns annularly in-filled with Self Compacting Concrete (SCC) of grades M25, M30 and M35 and yield strength of steel tubes 250MPa and Six specimens of RCC (SCC) columns. The effect of grade of in-filled concrete tested for axial load, various factors such as load-deflection, stiffness, failure mode, confinement of concrete, ultimate compressive strength and ductility are experimentally studied and reported. The experimental results of DSHCFT are also compared with European Code 4 and found that the code predicts conservatively. The comparison was also extended over ultimate strengths of DSHCFT columns with their RCC (SCC) counter parts and reported.

KEYWORDS DSHCFT, SCC, Load – deflection, Stiffness, Ultimate Load.

INTRODUCTION

Globally steel-Concrete composite structural members have been the interest of researchers over the past 30 years. The steel-concrete composite columns posses many advantages such as increased speed, forming an integral structural part of main structure, higher capacity, good fire resistance, etc., The efficiency in strength, ductility and energy absorption make them opt to resist forces due to earthquake and hence they are found feasible for high rise structures, bridge piers and heavy loaded structures. Among the steel concrete composite columns, the Concrete Filled Tubular columns (CFT) and Double Skinned Hollow Concrete Filled Tubular columns (DSHCFT) have been the particular interest of some researchers in the recent past. Referring to the literature, Stephen P. Schneider (1998) identified that Local buckling of circular columns occurred at an axial ductility of 10 or more. M. Elchalakani et al., (2002) at the final stage of elastic region, there is a bond loss between steel and concrete. S. Ramana Gopal, P. Devadas Manoharan (2004) studied that concrete filled tubular columns showed large enhancement in load carrying capacity compared to the steel hollow tubular columns. E.K. Mohanraj (2008) compared ACI /As codes with the experimental ultimate compressive loads of CFT columns with various in-fill materials. Kojiro Uenaka et al., (2010), observed that the experimental strength was mostly larger than the simply super posed estimation of steel tubes and sandwiched concrete. Fa-Xing Ding et al., (2011), concluded that the confinement effect, ultimate strength and ductility of the column increase with increase in steel ratio and steel strength. C.X. Dong and J.C.M. Ho (2012), concluded that measured elastic stiffness of Double skinned circular in-filled columns are 25.8% higher than their counter parts concrete filled circular columns. Jin-Hook kim., et al. (2013) opined that inner tube resistance to the Ultimate axial compressive load is negligible. From the comprehensive literature review DSHCFT columns in-filled with SCC using local materials is not evidenced. The objective of this experimental work is three fold.

Firstly, to study the effect of variation of three grades of Self Compacting Concrete in-fill on the behaviour of DSHCFT column subjected to axial load experimentally arrive at the ultimate load carrying capacity of such columns. Secondly, to verify the experimental ultimate loads with Euro Code 4 (EC4-1994) predictions. Finally, to compare the ultimate load thus experimentally obtained with the ultimate load capacity of the RCC stub column counterparts. While the Code guidelines for the design of composite columns yet to be released in India., this research recognizes its importantance.

MATERIALS AND METHODS

SPECIMEN FABRICATION

A typical cross section of a DSHCFT column is shown in Figure.1.

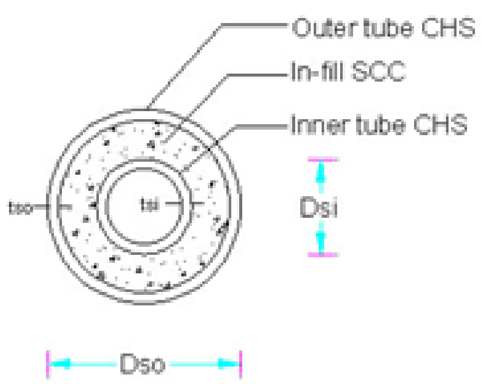

Figure. 1. DSHCFT column

Circular tubes of specified diameter were rolled from cold form sheets of average thickness 1.6mm (14 SWG) and cut to 500mm length welded by arch welding along their length. The thickness was selected satisfying ACI code (ACI 318-1995) limits on the width-to-thickness (B/t) ratio to avoid premature local buckling. Materials used were, Portland cement 53 grade (BIS 12269-1987), fine aggregate -sand (zone II of BIS 383-1970), hard granite broken stone of size 12mm and down from Bhavanisagar quarry having specific gravity of 2.59. Class 'F' Fly ash (BIS 3812-1981) obtained from Mettur thermal power station, potable drinking water, Water Retarding and Viscosity Modifying Admixtures available in the market namely Conplast SP 430 and Glenium stream – 2 respectively were used. The designed mixes are given in Table.1. The geometry details of the specimens are presented in Table.2.The mechanical properties of concrete from average of three cube compressive strength and steel three coupon tests are presented in Table 3.

FABRICATION OF RCC (SCC) SPECIMENS

Three reference RCC (SCC) columns with each 6 nos. of 12mm diameter. as longitudinal reinforcement tied with 6mm laterals @ 114 c/c were fabricated. The value of yield stress (fy) for both the longitudinal reinforcement and lateral ties were 415MPa. Here, the area of reinforcement (Asr) was taken as nearest possible equivalent to that of the total steel area obtained as a sum of the inner and outer tubes area of the DSHCFT specimens.

CASTING

SCC mixes with measured quantity (Okamura 2003 and European Guidelines 2005) was prepared by mixing manually and then filled in the annulus of the DSHCFT specimens. The RCC (SCC) specimens were cast in PVC moulds. No compaction was done. On the next day of casting the PVC moulds from RCC (SCC) specimens were carefully removed. All the DSHCFT specimens were cured in shaded room using moist curing by covering with wet cloths. The RCC specimens were cured by immersion curing. After 28 days the specimens were visually checked, small level reductions due to shrinkage of concrete were finished with a thin layer of plaster of paris. After painting, the specimens were tested.

SPECIMEN DESCRIPTION

Two identical DSHCFT specimens formed one single group named as, G1-M25, similarly G2-M30 and G3-M35 are named. In the RCC (SCC) specimens, R1-M25 refers 2 numbers specimen, and R2-M30, R3-M35 refer each two specimens.

TEST SETUP AND PROCEDURE

The entire tests were carried out using 1000kN electronic universal testing machine at Government College of Technology, Coimbatore. Tamilnadu, India. One loaded specimen is shown in figure. 2. An initial load of about 5 kN, was applied to fix the specimen. Magnetic type dial gauges were used to measure the deflections at mid span and at L/5 distance from ends. For each load increment of 10 kN axial compression, both the longitudinal and lateral deformations of the specimens were measured. All specimens were subjected to load up to failure. Each specimen test consumed almost an hour. All the specimens were loaded tested up to failure; the test progressed without any sudden bursting.

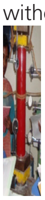

Figure 2. Loaded Specimen

COMPARISION WITH EURO CODE (EC4-1994)

Eurocode 4 (EC4) adopts limit state concepts covers both concrete encased and partially encased steel sections and concrete – filled sections with or without reinforcement. EC4 admits serviceability and safety aspects with partial safety factors to loads as well as material properties. In the code, inclusion of confinement effects for circular columns must be made if the relative slenderness value $\bar{\lambda}$ is less than 0.5, where $\bar{\lambda}$ is

$$\bar{\lambda} = \sqrt{N_{pl,R} / N_{cr}}$$

Where,

$$N_{cr} = \pi^2 (EI)_e / l^2, \quad (EI)_e = E_a I_a + 0.8 E_{cd} I_c, \qquad (2)$$

$E_{cd} = E_{cm} / \gamma_c, E_{cm}$ is the secant modulus of concrete (given by clause 3.2.4.1 and Table 3.2) in EC4, $\gamma_c = 1.35$ is safety factor (given by clause A.3.1 and A.3.4 EC4). The value of $\bar{\lambda}$ for 114 mm circular columns was arrived at as 0.18. Hence, the confinement effects must be included in design calculation. So, the equation of ultimate axial load for circular columns is,

$$N_{pl,R} = A_a \eta_2 f_y + A_c f_c [1 + \eta_1 (t/d)(f_y / f_c) \qquad (3)$$

Where, A_a and A_c are the area of steel and concrete, f_c and f_y are the strength of steel and concrete and t and d are the thickness and diameter of the tube. $\eta_1 = 4.9 - 18.5\bar{\lambda} + 17\bar{\lambda}^2$ and . $\eta_2 = 0.25(3 + 2\bar{\lambda})$ The values of the Ultimate load resistance calculated using equations (1) (2) and (3 vith confinement effect thus calculated presented in table .4

Figure 3. Tested DSHCFT specimens

RESULT AND DISCUSSION

FAILURE MODES

In all the G1, G2 and G3 groups the visible overall buckling followed by local buckling occurred around 85 to 90% of the ultimate load. The local buckling of outer tubes bent outward, either at middle of the span or at any one end. The inner tube also folded inward at the same section where bent occurred in the outer tube. The formation of ring like fold occurred on the compressive flange of the overall buckling. The reference RCC (SCC) specimens failed due to crushing at the end. The tested DSHCFT specimens with failure modes are shown in figure.3. No splitting failure or bursting of tubes occurred on the welded lines of the DSHCFT specimens.

LOAD DEFLECTION CURVE

The DSHCFT specimens of all the groups showed fairly ductile behaviour. Load Vs Midspan deflection is presented in figure.4. The initial shift from elastic to elasto-plastic region took place around 70% to 75% of ultimate load. At about 85% to 90% of ultimate load strain hardening started. All the three groups had their strain hardening zone. The deflection range from elastic state to the ultimate state was almost 3 times and above.

STIFFNESS

On comparison G3 specimens were found to have more stiffness, compared to G2 and G1 specimens. The stiffness of DHCFT specimens were found to be almost more than double the stiffness of RCC-SCC. The stiffness values of the DSHCFT specimens are shown in the table.4 and the stiffness values of RCC-SCC specimens are presented in table.5

DUCTILITY INDEX

The ductility index of the columns is herein defined as the ratio of the deflection at ultimate or peak load to the deflection corresponding to the yielding of the extreme fibre in the compression zone. (E K Mohanraj and Dr S Kandasamy 2008). The ductility index values of the specimens are shown in Table. 4. It can be noted that the ductility of DSHCFT SCC in-filled specimens had higher ductility for lower value of grade of in-filled concrete.

ULTIMATE COMREIVE LOAD

It can be noted that the G1, G2 and G3 specimens predicted with increasing ultimate compressive load as the grade of the infill increased. The experimental ultimate compressive loads of the DSHCFT specimens were compared with EC4 predictions and presented in table 4. Also, the experimental ultimate compressive loads of the reference RCC (SCC) specimens are compared with DSHCFT specimens and presented in the Table 5.

CONFINEMENT
The term confinement factor is given by the equation,

$$\xi = A_{so} f_y / A_{c\ nominal} f_c \qquad (4)$$

The calculated values of ξ as per equation (4), for the DSHCFT specimens are given in Table 2. Previous researcher (Lin-Hai Han et al., 2004) opined that an increase in confinement factor gives rise to the increased value of ultimate axial compressive load. From Table 2, G3 has the lesser confinement factor, in table 4, G3 group resulted with higher ultimate load. So, constraining other parameters in specified range, it is noted for DSHCFT columns in-filled with SCC, increase in grade of concrete increases the ultimate load.

CONCLUSION
Within the scope of the experiments made, the following conclusions are drawn:

The failure mode of the DSHCFT specimens were over all buckling followed by local buckling of outer tube outward and inner tube inward, either at the mid height or at top or bottom ends.

Higher stiffness and ultimate load of DSHCFT columns with SCC can be had by increasing the grade of concrete. The stiffness of DSHCFT SCC in-filled stub columns was in the range of almost twice than that of their RCC-SCC counterparts.

The lower grade of in-fill leads to higher ductility.
On comparison with the experimentally observed values of axial ultimate compressive load of the DSHCFT specimens, the Eurocode 4 predicted with a margin of 17% conservation in all the three groups. So, for the design of DSHCFT columns in-filled with SCC, EC4 guidelines may be applied safely.

The DSHCFT stub columns posses' 90% higher capacity than their RCC counterparts made of M25, M30 and M35.

List of symbols
Ac, Aa : Area of concrete and total area of steel inner and outer tubes respectively

Aso : Area of outer steel tube

Asr : Area of steel reinforcement in RCC-SCC columns ; DI : Ductility Index

DSHCFT: Double Skinned Hollow Concrete Filled steel Tube columns

Dso : Outside diameter of outer steel tube (Given by EC4 as 'd')

Table 1. Mix Design (1 m3)

Grade	Cement (Kg)	Fine aggregate (Kg)	Course aggregate (Kg)	Flyash (Kg)	Gelinium stream-2 (% of powder content)	Conplast SP (% of powder content)	Water (Kg)	W/Cm (Cm=C+FA)
M25	573.6	756	775	152.25	0.3	5.5	304.82	0.42
M30	580	690	720	158	0.33	5.8	310	0.42
M35	612	676	705	162	0.36	6.2	314	0.41

Table 2. Geometric details of specimens

Specimen ID	Dso xtso (mmxmm)	Dsi x tsi (mm)x(mm)	ξ
G1-M25	114x1.63	40x1.63	0.73
G2-M30	114x1.63	40x1.63	0.61
G3-M35	114x1.63	40x1.63	0.52
	Diameter (mm)	Asr (Sq.mm)	
R1-M25	114	678	-
R2-M30	114	678	-
R3-M35	114	678	-

Table .3 Mechanical Properties of SCC and Steel

Material	fck (MPa)	Ec (MPa)	Ft (MPa)	fy (MPa)	Es (MPa)
Concrete M25	25.76	2.6x104	2.94	–	–
Concrete M30	31.16	3.2x104	2.97	-	-
Concrete M35	36.38	3.4x104	2.98	-	-
Cold formed Steel Skin Sheets	–	–	–	252	2.05x105
Reinforcements Steel for RCC (SCC)	-	-	-	415	2.06x105

Table 4. Verification of Experimental loads of DSHCFTs with EC4 code

Specimen ID	Nue (kN)	NEC4 (kN)	NEC4/Nue	Ductility Index	Stiffness (kN/mm)
G1-M25	470	389	0.83	4.16	36
G2-M30	510	421	0.84	4.08	58
G3-M35	560	454	0.81	4.00	80
Average			0.83	-	

Table 5. Comparative capacity of RCC -SCC with DSHCFT specimens

Specimen ID	Nue (kN)		DSHCFT / RCC - (SCC)	Stiffness (kN/mm)
	RCC (SCC)	DSHCFT		
R1-M25	260	470	1.81	23
R2-M30	280	510	1.82	24
R3-M35 295 560			1.89	25
Average			1.90	-

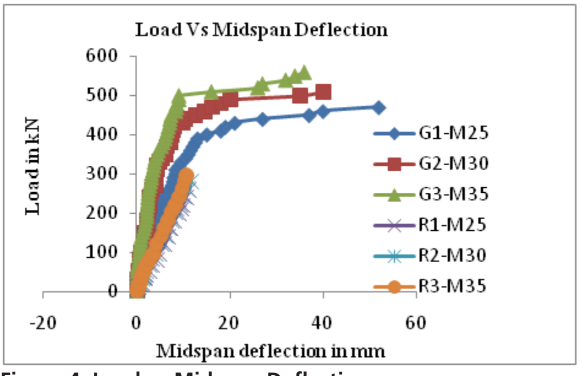

Figure 4. Load vs Midspan Deflection

Dsi : Outside diameter of inner steel tube

Ea : Modulus of elasticity of the steel section

(EI)e : Effective elastic flexural stiffness of a composite cross-section

fck: Concrete Characteristics cube compressive strength

fc: Cylinder compressive strength of concrete (0.8fcc)

fy : Yield strength of steel

Ia, Ic: M.I of the steel section and uncracked column section respectively

NEC4 : Ultimate axial load of the DSHCFT column as per EC4

Nue : Experimental Ultimate axial load

tso : Thickness of outer steel tube

tsi : Thickness of inner steel tube

l : Effective length of a column

$\bar{\lambda}$: Relative slenderness as per EC4

ξ : Confinement coefficient

η_1, η_2: Co-efficient of Confinement for concrete and steel respectively. γ_c: Safety factor

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