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Tests on Double Skinned Steel Tubular Concrete In-Filled Columns

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ABSTRACT

This paper presents the experimental study of six Double Skinned Tubular in-filled Columns. Out of which three are empty and the remaining three are filled with Self Compacting Concrete (SCC). The specimens have Do/to ratio varying from 57 to 80 and Di/ti ratio varying from 29 to 57. The hollowness ratios of the in-filled specimens were 0.43 and 0.67. The skin tubes of hot rolled pipes available in local market Coimbatore, Tamil Nadu were purchased and used. The grade of in-filled concrete used was M 25 and that of the steel was Fe 250. The columns were tested for Failure mode, Load Vs Axial deformations and Ultimate load and reported. The experimental ultimate loads obtained were compared with theoretical ultimate load calculated as per Eurocode 4 (EC4) and also the Ultimate load as per simple superposition model. The comparison is also presented. Concrete confinement is evidenced from superposition model. Based on the experiments, suggestions for future researches are also presented.

Keywords: *Axial Load, Concrete, Double skinned, Failure mode, Local Buckling, Ultimate Load*

1. Introduction

Double steel tubes of same or different cross sectional shapes arranged concentrically and concrete filled in their annular space are known are known as Double Skinned Hollow Concrete Filled Tubular (DSHCFT) columns. Shakir kalil1 verified suitability of use of application of double skinned tubular columns with reference to BS 5400. M.Elchalakani et al.,2 identified that at ultimate loading, gauge measurements was not susceptible for both steel and concrete. However, he concluded that concrete cracking may induce extra deformations and at the elastic limit, it was expected that bond loss between steel and concrete. Zhong Tao et al.,3 opined that D/t ratio is not directly proportional to the ductility and confinement is proportional to the ductility. Jin-Hook kim., et al.,4 The effect of inner tube to load resistance at Ultimate stage is trifling. E. K. Mohanraj et al.,5 verified different infill

List of Notations

Aa, $A_{c:}$ Area of -outer steel tubes, $A_{c:}$ area of in-filled concrete

$D_{o,}$ D_i: Diameter of outer and inner tube of outer steel tube

f_{ck}: Characteristics cube compressive strength of concrete

f_c: Cylinder compressive strength of concrete ($0.8f_{cc}$)

f_y : Yield strength of steel; n1,n2: Confinement coefficients.

N_{EC4} : Ultimate load as per EC4;

$N_{exp:}$ Experimental ultimate load

$N_{sup:}$ Ultimate load by superposing strength of concrete and steel

t_o, t_i: Thickness of outer and inner steel tube;

$t_{c:}$Thickness of in-fill concrete;

L : Effective length of a column;

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

χ: Hollowness ratio ($= D_i/ (D_o - 2t_o)$),

ξ: Confinement Coefficient ($=A_{so}.f_{so}/A_c.f_{ck}$)

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materials in CFT columns. There is no proper code guideline in India till date for the design of composite columns. In these paper, experimental findings of axial load test made on the Double skinned empty columns and columns in-filled with self –compacting concrete are presented.

2. Materials and Methods

2.1 Specimen Fabrication

2.11 Steel tubes

For outer and inner skins, steel tubes available in the local market Coimbatore, Tamil Nadu, India satisfying thickness needed as per ACI 318-1995 code[6] to avoid undue local buckling, were cut to the desired length. The steel tubes were cut and both the pipes were kept concentrically on a base plate, to fill concrete.

2.12 Concrete Casting

The table.1 is the materials used for preparing 1m^3 of concrete.

Table.1 Materials for 1 m3 of concrete

Cement + Flyash (kg)	Sand (kg)	12mm Course aggregate (kg)	Water (Litres)	WRA (%)
420 + 152	776	757	176	5.5

Mechanically mixed SCC mix of measured quantity as per European Guidelines 2005[7] was then filled in the specimens. The samples were cured in controlled humid condition for 28 days. Small level reductions at ends of specimens due to shrinkage of concrete were found and finished with a thin layer of plaster of paris, well in before the testing.

2.13 Companion Specimens

Cubes of 150 mm size, cylinders of 150 mm x 300 mm, and 100 mm x 100 mm x 700 mm plain beams are cast in each 6 numbers and the results of average values pertaining to 28 days of immersed curing are presented in table 2.

Table.2. Design Parameters

f_{ck} (MPa)	F_{ct} (MPa)	f_{cr} (MPa)	Ec (MPa)	Es (MPa)
26.71	2.67	3.41	2x104	2x105

2.2 Specimen Nomenclature

All specimens were of same length 500 mm and they are labeled serially as S1 to S6 with an alphabet of E or F followed it. Where, E refers empty and F refers annularly in-filled with SCC. The specimens S1E, and S2F are similar in a way that their inner and outer tubes are connected by four horizontal mild steel stiffeners of diameter 3mm arc welded at their ends. Similarly, S4E and S5E were also stiffened, whereas, the specimens S3F and S6F were not stiffened at ends.

2.3 Test setup and Procedure

The entire tests were carried out using 3000 kN compression testing machine at Sri Ramakrishna Mission Vidyalaya Polytechnic College Coimbatore. Tamil Nadu, India. The test arrangement and instrumentation are shown in figure 1. At top and bottom ends a pair of Non-straining hinge plates made of mild steel 50 mm thick holding 40 mm steel ball in between them were placed, to simulate hinged ends condition. An initial load of 5 kN was applied to hold the specimen upright. Magnetic type dial gauges were used to measure the deflections at mid span. Both the longitudinal deformations of the column specimens were measured from digital display connected to the machine.

Figure. 1 -Test Arrangement.

Axial compressive load was applied in an increment of one tenth of the predicted load capacity. For each load increment, the deformations were recorded. All specimens were subjected to load up to failure. Each specimen test consumed almost an hour.

2.4 Theoretical Calculations

The theoretical calculations were made as Eurocode 4 recommendations. It offers guide lines for the proportioning columns of composite nature with a) concrete encased, b) partially encased steel sections and c) concrete in-filled tubular sections either with or without reinforcement. In this code, effect of long-term loading is separately considered. Partial safety factors are adopted for load and materials, to ensure more effective service and safety. By the code the ultimate axial compressive load is calculated using the following expression,

$$N_{EC4} = A_a n_2 fy + A_c f_c \left\lfloor 1 + n_1 (t/d)(f_y/f_c) \right\rfloor (1)$$

Where $n_1 = 4.9 - 18\bar{\lambda} + 17\bar{\lambda}^2$ and

$$n_2 = 0.25(3 + 2\bar{\lambda})$$

Along with EC4 codes, using the superposing models the theoretical calculations are done. Superposing model uses the simple summation of the load carrying capacity of Inner and out steel and load carrying capacity of in-filled concrete and the values of geometry details of specimens are presented in table 3, values of confinement factor and ultimate compressive load are shown in table 4.

Table.3 Geometry details

ID	Do/Di (mm) / (mm)	to/ti (mm) / (mm)	Do/ to	Di/ ti	χ
S1E	114/74	2.03/2.03	57	37	0.67
S2F	114/74	2.03/2.03	57	37	0.67
S3F	140/58	2.03/2.03	70	29	0.43
S4E	160/114	2.03/2.03	80	57	0.73
S5E	160/114	2.34/2.03	68	57	0.73
S6F	140/58	2.03/2.03	70	29	0.43

Table.4 Confinement & Ultimate Load

ID	ξ	N_{EC4} (kN)	N_{ue} (kN)	N_{EC4} / N_{ue}	N_{sup} (kN)	N_{sup} / N_{ue}
S1E	N/A	294	308	0.95	289	0.94
S2F	0.71	428	584	0.73	425	0.73
S3F	0.57	688	887	0.75	615	0.69
S4E	N/A	427	394	1.08	424	1.08
S5E	N/A	473	404	1.17	466	1.15
S6F	0.57	668	770	0.87	615	0.80

2.5 Failure modes

Figure 2a and Table 5 shows the failure mode of all specimens. All specimens predominantly failed by local buckling at top end or at bottom end. No failure markings located in the mid height region. The inner tubes failure are shown for all in-filled specimens S2, S3 and S6 in figure 2b. It can be seen that the inner plate folded inward as series of chords almost at the same section where external plate locally buckled. The failure of this kind in the inner plate may be due to shear compression.

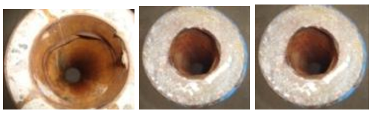
Table 5. Failure modes

ID	L/D_o	Failure mode	Spot (*)	Shape / Formation
S1E	4.4	LB	B	Elephant foot
S2F	4.4	L.B	T	Outer tube Crumbling
S3F	3.6	L.B	B	Elephant foot
S4E	3.1	L.B	B	Elephant foot
S5E	3.1	L.B	B	Successive folds
S6F	3.6	L.B	T	Elephant foot

NOTE:(*) L.B: Local Buckling T: Top; B: Bottom

The figure 2c shows the failure of outer tube in the specimen S5E local buckling similar to elephant foot buckling. However, a little consideration will show that the specimen S5 is having the subsidiary failures in the form of a sort of folded ribs along the mid height of the specimen.

Figure. 2a - Specimens after testing



S2F S3F S6F

Figure. 2b -Failures of inner tubes

S5E

Figure. 2c. - Failure in outer tube

2.6 Load Vs Axial Deformation

The figure 3 shows Load Vs Axial deformation. Up to 82 % of peak load, the initial stiffness was present for empty model. Up to 87% of peak load, the initial stiffness was there for all in-filled models up to peak load, after the peak load the strain softening takes place in a steep manner.

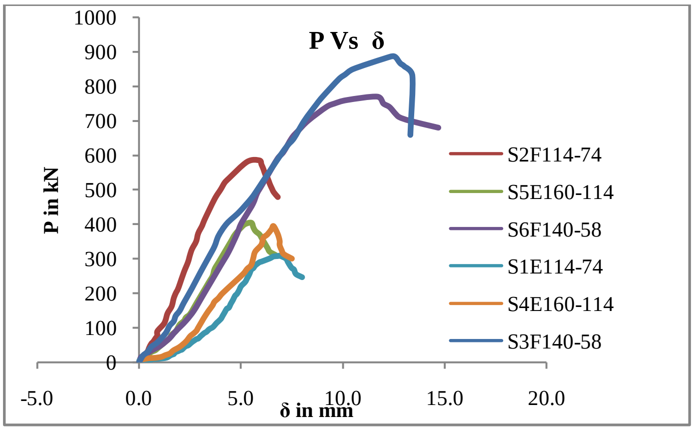


Fig. 3 - Load Vs Axial Deformation

In general up to peak load around, 70% of total deformation took place. Then, slowly after reaching maximum load, the strain softening in descending portion existed up to 75% of the ultimate load.

2.7 Experimental Ultimate Compressive Load

The experimental ultimate compressive load for the models are presented in figure.4.

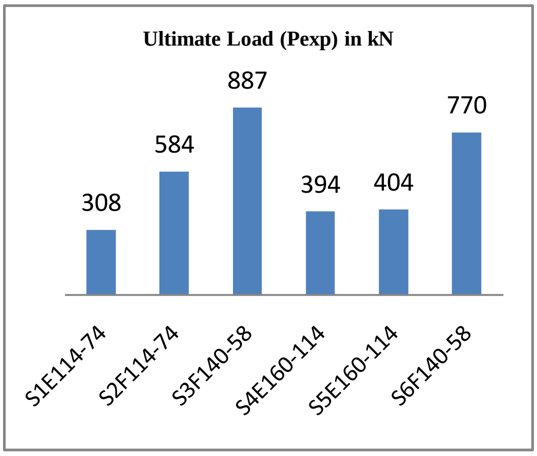


Fig. 4 - Ultimate compressive strength

3.0 Results and Discussion

The tested samples were possessing values of aspect ratio L/D_o from 3.1 to 4.4; so they are termed as intermediate columns. These columns do not experience global failure or over all failure, instead the material failure in the form of local buckling only took place. In the cases of t_o = or > t_i, the failure sequences are assumed as yielding of outer plate, followed by the bonded in-filled concrete subjected to yielding and it further extended to inner plate also. If t_o < ti, the vice-versa could have been possible. S2F being the stiffened specimen at ends, the local buckling of outer tube was not so deliberately visible. However, at its top end, over the depth roughly below t_c, the failure can be noticed by careful verification. As far the Load Vs Axial deformation is concerned, it was noted in general that until the ultimate load was reached around 73% total deformation only took place. Compared among the in-filled specimens, S2F had more initial stiffness than that of S3F and S6F, the apparent reason is lesser $D_{o/to}$ ratio . Regarding ultimate load, the empty specimens, larger than 114 mm diameter, referring to S1E, S4E and S5E both resulted in lower load than that calculated by N_{EC4} and N_{sup}. This indicates that those specimens need more stiffening along the length that is over and above the end stiffeners. However, this needs to be verified by some more tests. In double skinned in-filled columns application, application of load on steel alone also needs careful verification. Because, steel is considered to be form work before in-filling is done. Hence, this verification is considered vital.

4.0 Conclusion

Within the scope of this investigation, the following conclusions are drawn:

Load deformation character is presented as a plot of Load Vs Axial Shortening. The comparison of the experimentally observed axial ultimate compressive load showed conservative prediction of Eurocode 4 (EC4[7]) for S2F, S3F and S6F, at 27%, 20% and 13% respectively. In general, EC4 code over estimates the ultimate load of empty specimens with D_o/t_o ratio more than 57 at 15% to 20%. The EC4 and superposition models both over estimate the Ultimate load for the empty specimens having larger value of D_o/t_o ratio than 57, from 8 to 17 %. The confinement of concrete is evident from the conservative results of in-filled specimens by superposition model.

5.0 Future Scope

Double skinned hollow columns without filling with various cross sections and various lateral connections can be studied. In the filled columns, for inner tubes only stiffened tubes or tubes with external ribs can be experimented. For outer tubes and inner tubes with vertical stiffeners using tangential or radial in section can be verified. Double skinned in-filled columns with external rings may be tested.

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Conflict of Interest:

The authors declare that there is no conflict of interest regarding the publication of this paper.

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