Experimental Study on Comparison of Square, Rectangular and Circular Concrete Filled Steel Tube Composite Columns

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Abstract: ***Composite column is very much effective in providing strength, stability and stiffness. Many of developed countries are using composite column in construction because of providing advantage of speed in construction. In this particular paper, an experimental study in which total seventy-two steel tube specimens were tested. The purpose of this study is to observe the behavior of different types of concrete filled steel tube (CFST) composite column like square, rectangular and circular having various grades of concrete M20 and M40 and varying H/D ratio of column specimens under axially compressive load. Ductility Index, Strength Index, Concrete Contribution Ratio are calculated. Also, comparison is made with steel hollow tube section.***

Keyword - Concrete filled steel tube, Composite column, Ductility Index, Strength Index, Concrete Contribution Ratio

I. INTRODUCTION

A steel-concrete composite column is compression member which is constructed using steel and concrete combination An attempt to utilize its beneficial properties of each material. Concrete-Filled Steel Tube (CFST) columns are becoming increasingly popular for column constructions of tall buildings due to the composite action between steel and concrete. It will help to structure under compression as well as in tension. In a recent scenario it would be better to provide high-rise construction because of answering to population growth and availability of limited land space. The vertical development is one of the best architect answers to it. Composite construction is the most favorable aspect to fulfil all the basic and most required aspects like strength, stability and stiffness. Steel-Concrete composite column are mainly categorized in three group fully encased section, partially encased and CFST section.

In a recent trend, it is important to enhancing flexibility of floor space by reduce column section size. By using composite column, there is no need to provide large column size and additional formwork to column because of hollow steel tube around the concrete. In this research paper, high yield strength steel is used, it has yield strength of 310 MPa. Grade 310 has high temperature resisting with good ductility properties. In this present work, different grades of concrete like M20 and M40 are filled in three types of steel tube sections like square, rectangular and circular with varying *H/D* ratio 3, 5 and 7 under axially load. Area of cross-section of steel tubes are more or less same.

II. EXPERIMENTAL WORK AND MATERIALS

2.1 Materials

The materials used in this experimental work are as follow:

Cement: Ordinary Portland Cement having grade of 53 confirming to I.S.1489:1991 is used in this experimental work.

Fine Aggregate: Locally available sand is used to have Zone- I with specific gravity 2.70 and fineness modulus 3.03 confirming to I.S.383:1970.

Coarse Aggregate: Crushed coarse aggregate having 10mm size is used to have specific gravity of 2.61 confirming to I.S.383:1970.

Superplasticizer: To get good workability in concrete, Superplasticizer named MasterPel777 liquid is used. Dosage has been taken 0.5% by weight of cement.

Steel tube section: Three different sections of steel tube are used square, rectangular and circular in this experimental work having 4.5mm wall-thickness for each confirming to I.S. 4923:1997.

2.2 Experimental Program

M20 and M40 grades of concrete are used in casting of total 54 numbers of CFST specimens having three types of sections like square, rectangular and circular with varying its *H/D* ratio of 3, 5 & 7 (Refer Table 1). Steel-wall thickness is 4.5mm which is same for all sections and also all sections have more or less equal area of cross-section of steel section. There are 18 hollow steel tube specimens are also compared with CFST. Total 72 numbers of steel tube section are tested under axial compression load. A vertical deformation is recorded with help of digital dial-gauge frequently at the interval of 50kN increase in axial load. Also, Its Strength Index (SI), Ductility Index (DI) and Concrete Contribution Ratio (CCR) are calculated.

Table 1 Experimental program

Section	Dimension (mm)	Area of Cross-section (mm^2)	*H/D*	Height (mm)	No. specimen	Total
Square	91.5×91.5	1514	3	274.5	8	72
			5	457.5	8	
			7	640.5	8	
Circular	114.31	1550	3	342.9	8	
			5	571.5	8	
			7	800.1	8	
Rectangular	122×61	1514	3	183	8	
			5	305	8	
			7	427	8	

2.3 Steel Properties

All the steel tubes are made from mild steel. Important parameters of steel tube like its dimension, cross-section area, yield strength, moment of inertia, modulus of elasticity according to I.S 4923:1997 are shown in Table 2.

Table 2 Steel tube properties

Parameter	Square	Rectangular	Circular
Dimension	91.5 × 91.5 mm	122 × 61mm	114.31mm
Area of Cross-Section (As) (mm^2)	1514	1514	1550
Yield Strength (MPa)	310	310	310
Moment of Inertia (mm^4)	187.36×10^4	93.78×10^4	234.36×10^4
Modulus of Elasticity (N/mm^2)	2×10^5	2×10^5	2×10^5
Thickness (mm)	4.5	4.5	4.5

Figure 1 Setup Circular and Square CFST

III. RESULTS AND DISCUSSION

As discussed earlier, total 72 specimens are tested in which 54 are concrete-filled steel tube and 18 are steel hollow tube sections.

3.1 Axial Load versus Deformation

Designation of sections, e.g. C3-M20 where C is for circular section, 3 is for *H/D* ratio & M20 is grade of concrete. CH-3 represents circular hollow section with *H/D* = 3

Table 3 Measured Average Result of Square, Rectangular and Circular Specimen

Section	Pu (kN)	Vertical Deformation (mm)	H/D	Grade of concrete	Pu(EC4)
C3-M20	759.0	9.1	3	M20	619
R3-M20	681.0	10.2	3	M20	550
S3-M20	795.0	8.2	3	M20	580
C5-M20	676.8	9.6	5	M20	619
R5-M20	661.8	11.2	5	M20	550
S5-M20	751.5	8.4	5	M20	580
C7-M20	673.2	10.0	7	M20	619
R7-M20	657.0	11.3	7	M20	550
S7-M20	742.2	8.7	7	M20	580

C3-M40	838.2	8.8	3	M40	759
R3-M40	735.0	10.0	3	M40	630
S3-M40	871.8	7.7	3	M40	689
C5-M40	831.6	9.3	5	M40	759
R5-M40	721.8	10.4	5	M40	630
S5-M40	850.2	8.2	5	M40	689
C7-M40	824.9	9.5	7	M40	759
R7-M40	717.0	10.9	7	M40	630
S7-M40	837.0	8.5	7	M40	689
CH-3	419.4	5.3	3		480
CH-5	423.0	5.4	5		480
CH-7	426.6	7.0	7		480
RH-3	634.5	2.8	3		470
RH-5	607.5	3.2	5		470
RH-7	531.0	5.7	7		470
SH-3	675.0	5.3	3		470
SH-5	658.8	6.8	5		470
SH-7	633.6	7.8	7		470

Table 4 Comparison of average CFST results of M20 and M40 grade of concrete

CFST (M20)	Pu (kN)	CFST (M40)	Pu (kN)	Increase in Pu (%)	Decreases in Deformation (%)
C3-M20	759	C3-M40	838.2	10.43	3.72
C5-M20	676.8	C5-M40	831.6	22.87	3.71
C7-M20	673.2	C7-M40	824.9	22.54	5.15
R3-M20	681	R3-M40	735.0	7.93	2.60
R5-M20	661.8	R5-M40	721.8	9.07	8.21
R7-M20	657	R7-M40	717.0	9.13	3.58
S3-M20	795	S3-M40	871.8	9.66	6.02
S5-M20	751.5	S5-M40	850.2	13.13	8.21
S7-M20	742.2	S7-M40	837.0	12.77	2.35

Table 3 shows results arrived from testing of CFST section and hollow steel tube under universal testing machine. It is an average results of three CFST specimens and two for steel hollow tube. It is clearly shows that with increase in grade of concrete, there is increase in ultimate load carrying capacity of square, rectangular and circular steel tube. Furthermore, it is also noticed that square section has higher load carrying capacity as compared to circular and rectangular section. Also, load carrying capacity are compared with Euro code 4 design. Here, Pu is ultimate load during test, *H/D* is height to depth ratio and Pu (EC4) is load as per Eurocode 4 design.

Tables 3 & 4 show that for M20 and M40 grades of concrete, percentage increase in ultimate load carrying capacity of square CFST is 9.66%, 13.13% and 12.77% for *H/D* ratio 3, 5 and 7, respectively. For circular CFST, percentage increase in ultimate load carrying capacity is 10.43%, 22.87% and 22.54% for *H/D* ratio 3, 5 and 7, respectively. For rectangular CFST, percentage increase in ultimate load carrying capacity is 7.93%, 9.07% and 9.13% for *H/D* ratio 3, 5 and 7, respectively. Also, Tables show that square CFST has higher load carrying capacity as compared to rectangular and circular. Load carrying capacity decreases with increases in *H/D* ratio.

Rectangular CFST has high deformation as compared to circular and square CFST. Also, increase in deformation is observed with the increase in *H/D*. Table 4 shows that M40 grade of concrete CFST has less deformation than M20 grade of concrete in all types of CFST specimens. Square CFST has lowest deformation as compared to rectangular and circular CFST.

Figures 2-4 show the axial load versus deformation curve.

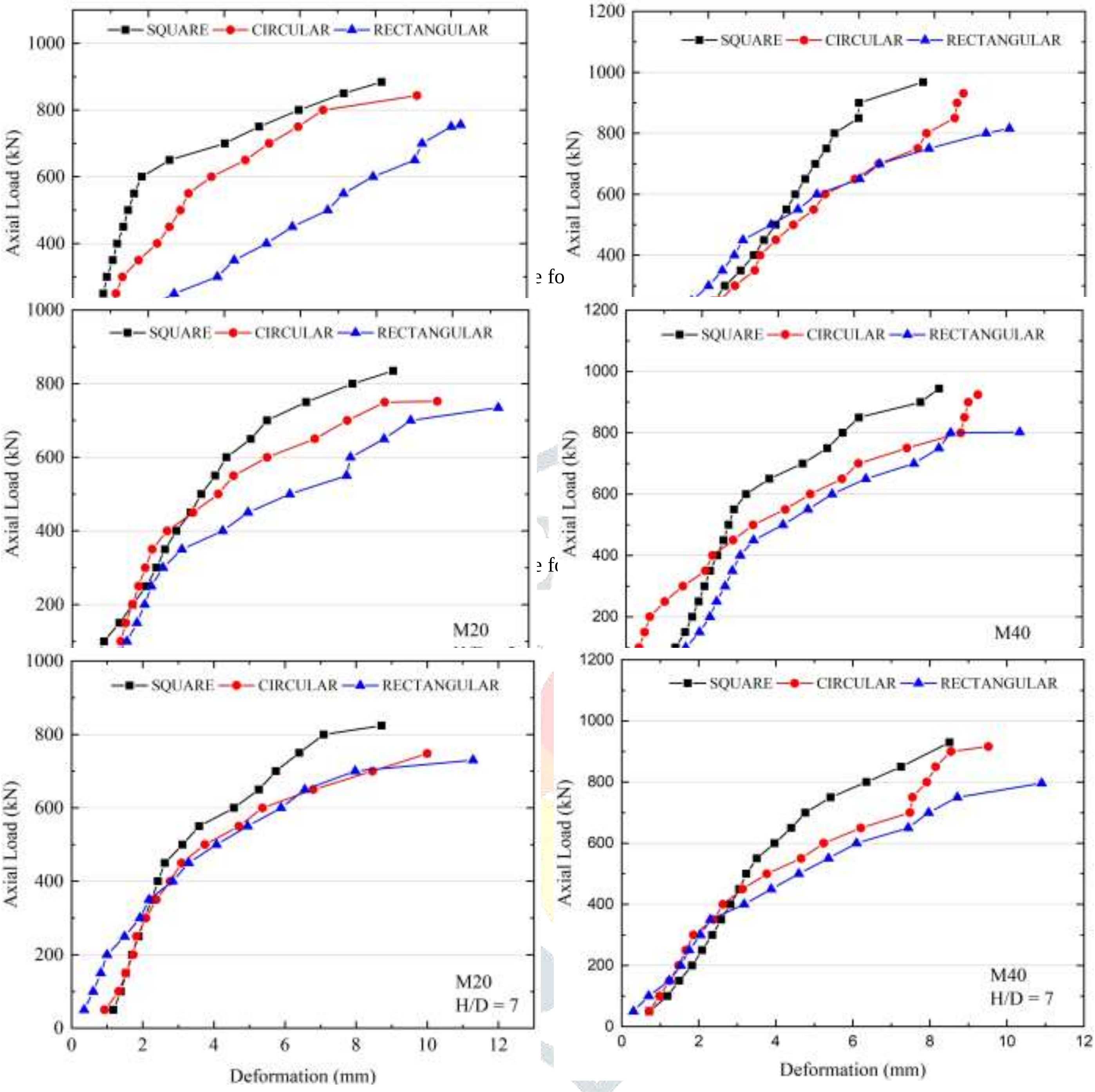

Figure 4 Axial load v/s Deformation curve for Rectangular, Square and Circular CFST (H/D = 7)

3.2 Performance Indices

Some important parameters are defined to calculate ductility and strength enhancement of CFST columns DI, SI and CCR are calculated using following Equations

$$DI = \frac{\delta_u}{\delta_{85\%}} \quad (1)$$

$$SI = \frac{N_{u,filled}}{A_C f_{ck} + A_s f_y} \quad (2)$$

$$CCR = \frac{N_{u,filled}}{N_{u,Hollow}} \quad (3)$$

where *Nu* (filled) is ultimate load of filled section; *Nu* (hollow) is ultimate load of un-filled section; $\boldsymbol{\delta}u$ is the vertical axial deformation at ultimate load; $\boldsymbol{\delta}_{85\%}$ is deformation when load falls to 85% of ultimate load; A_c and A_s is cross sectional areas of concrete and steel tube and f_y and f_{ck} are the yielding stress of steel and concrete characteristics strength, respectively.

Here, SI is described as the ratio of axial load capacity to sum of individual strength of steel section and concrete. CCR defined as ratio of load carrying capacity of concrete-filled section to hollow steel section generally it gives level of enhancement in strength by filling steel tube with concrete. DI is defined as ratio of deformation when load falls to 85% of ultimate load carrying capacity to deformation at ultimate load carrying capacity. The average SI, DI and CCR are shown in Table 5 for square, rectangular and circular CFST column.

Table 5 Average Performance Indices

Section	SI	DI	CCR
C3-M20	1.16	1.73	1.81
C3-M40	1.01	1.31	2.00
C5-M20	1.03	1.80	1.60
C5-M40	1.01	1.67	1.97
C7-M20	1.03	1.86	1.58
C7-M40	1.00	1.29	1.93
R3-M20	1.16	1.27	1.07
R3-M40	1.04	1.44	1.16
R5-M20	1.13	1.61	1.09
R5-M40	1.02	1.50	1.19
R7-M20	1.12	1.84	1.24
R7-M40	1.02	1.44	1.35
S3-M20	1.31	1.78	1.06
S3-M40	1.17	1.26	1.12
S5-M20	1.24	1.53	1.01
S5-M40	1.14	1.60	1.12
S7-M20	1.22	1.52	1.01
S7-M40	1.13	1.66	1.11

From the Table 4, it is clearly noticed that SI decreases with increase in *H/D* ratio in all types of section square, rectangular and circular. Also, circular CFST sections has higher CCR as compared to square and rectangular CFST. There is also increases in DI when *H/D* increases, as grade of concrete increases increase noticed in CCR. DI is greater than 1 indicate that specimen has good enough ductile which means it an resist large deformation prior to failure.

Figure 5 Tested circular CFST

Figure 6 Tested specimen for H/D = 7

IV. CONCLUSIONS

1) The ultimate load carrying capacity of Square CFST column is higher as compared to rectangular and circular CFST column.
2) Percentage increase in ultimate load carrying capacity of square CFST for having of M20 & M40 grade of concrete is 9.66%, 13.13% and 12.77% for *H/D* ratio 3, 5 and 7, respectively
3) For Circular CFST, percentage increase in ultimate load carrying capacity is 10.43%, 22.87% and 22.54% for *H/D* ratio 3, 5 and 7, respectively.
4) For Rectangular CFST, percentage increase in ultimate load carrying capacity is 7.93%, 9.07% and 9.13% for *H/D* ratio 3, 5 and 7, respectively.
5) Load carrying capacity decreases with increase *H/D* (3, 5, 7) ratio in all square, rectangular and circular CFST columns.
6) Square CFST column has higher SI as compared to rectangular and circular CFST.
7) Circular CFST has more CCR as compared to rectangular and square CFST.
8) As increase grade of concrete increases increase noticed in CCR.
9) SI decreases with increase in *H/D* ratio in all types of section square, rectangular and circular.

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