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Effect of Shape of Cross-section and Its Performance for Concrete Filled Steel Fluted Columns

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Abstract: *An attempt has been made to use this composite structural member as a column with a modification of flutes on the steel tube which enhances the aesthetics and development area of sheet by which the moment of inertia gets increased by about 17 to 40 % for rectangular flutes and 9 to 23 % for triangular flutes. Confining concrete by providing triangular and rectangular shape fluted steel tube has been investigated by a well planned experimental work on twenty six concrete filled steel fluted columns (CFSFC). The parameters chosen for the study are (i) Geometry of the specimen - Triangular fluted columns (TFC) and rectangular fluted columns (RFC) (ii) Different L/D ratios (size of the columns) (iii) Longitudinal reinforcement. Three series of specimens having different L/D ratios, 2500mm long have been tested with M20 grade of self compacting concrete (SCC). It is observed that the load resistance is better in rectangular fluted columns as compared to the triangular fluted columns by 1.31 %, 1.05 % and 9.92% respectively for L/D ratio of 15, 20 and 25. The moment of inertia gets increased by about17% to 40% for RFC and 9% to 23% for TFC.*

Keywords: *CFSFC, CFST, RFC, TFC, SCC, Composite Column.*

I. INTRODUCTION

CFST column technology evolved for the past forty years. Significant research has been made to understand the behaviour of CFST columns taking advantage of confinement avoiding the necessity of form work. Better resistance of loads by columns for axial strength has been achieved by confining concrete by steel tubes. It has been envisaged to study strength, stiffness and buckling characteristics by providing flutes to steel sheet of columns which enhances aesthesis of columns. Also, fluted columns enhances the strength and also stiffness as the surface area of steel sheet and moment of inertia of the column increases. The advantage of steel members having high tensile strength and ductility and concrete members having better compressive strength have been better made use as a composite member. Additional longitudinal reinforcement in the columns makes the columns still stronger. Hence, it has been envisaged to check whether such a columns would act as a slender column. Most of the researchers (1-18) have considered the effect of geometric properties like shape, l/d ratio, t/d ratio, boundary conditions, strength of materials and the loading conditions. It has been found that generally the failure occurs by either local buckling or yield failure. It has been found that Euro code gives a better design method which yields values nearer to experimental values. Studies performed on different L/D ratios with small eccentricities have yielded that the degree of confinement offered by a thin walled circular steel tube to the internal concrete is dependent on the load conditions. Other parameters that have been considered by many researchers are different loading conditions like earthquake load, repetitive load, impact load etc.

II. PREPARATION OF SPECIMEN FOR STEEL SHEET

Mild steel sheet with thickness 0.8 mm has been pressed in a mill to obtain five triangular flute with 10 mm at apex of triangle uniformly along the length. These sheets were given a tubular shape and tacked along the edges at an interval of 250 mm along the length of the column. The number and the size of the flutes remained same irrespective of the diameter of the column i.e., for different L/D ratios as shown in Fig 2.1. The moment of inertia gets increased by about 17% to 40 % for rectangular fluted columns and 9% to 23 % for triangular fluted columns are as shown in Table II**.** The development length of the width of each of these columns with different L/D ratios as compared to a circular column of the same diameter is 14, 18 and 22% for triangular fluted columns and 24, 29 and 34 % for rectangular fluted columns for L/D ratios of 15, 20 and 25 respectively as shown in Table III. Reinforcement cage is then placed inside these fluted tubes taking care to maintain the necessary cover. The five types of columns have been shown in Fig 2.2 and Fig 2.3 respectively. Though regular ties have not been used, however four ties have been provided at equal distances to keep the reinforcement in position. Self Compacting Concrete of design mix M_{20} designed as per Nan Su method(15) and tested for conformity as per IS specifications is poured into the fluted steel tube. These columns were cured for 28 days by frequently pouring water over top of the column. Pilot specimens cured in a similar manner were tested to know the basic properties and are entered in Table I. The transformed area and experimental load details are shown in Table IV.

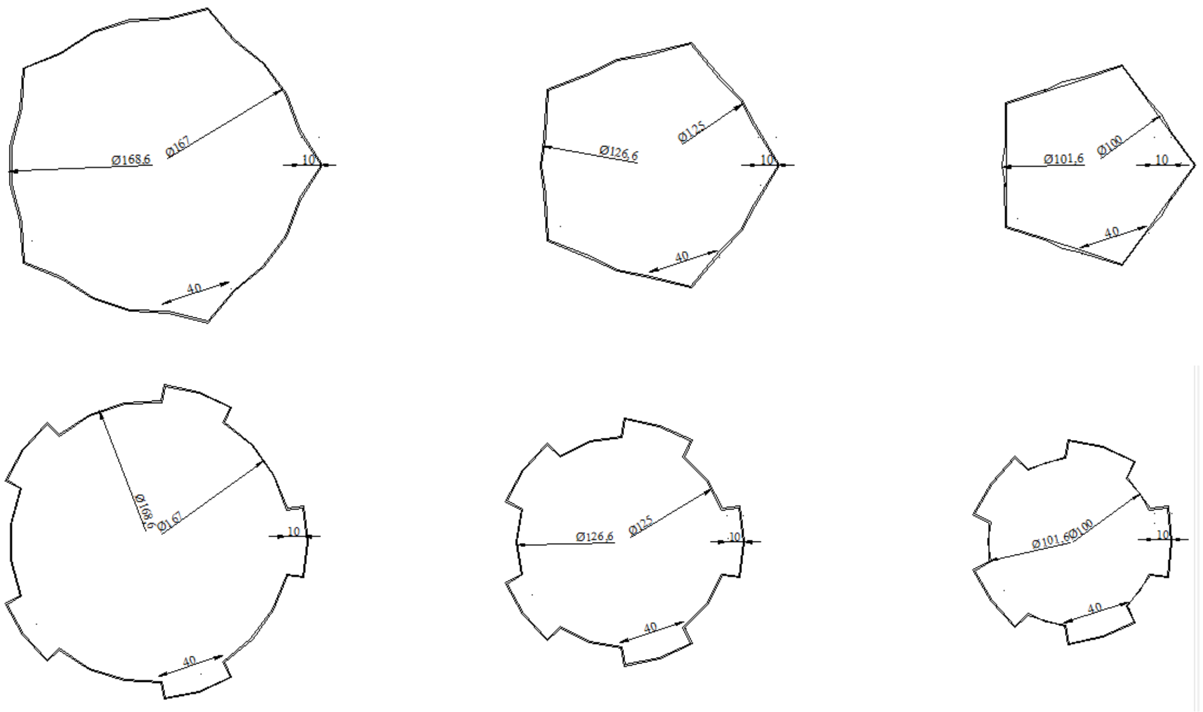

Fig 2.1 Cross section of TFC & RFC with L/D ratio of 15, 20 & 25.

III. EXPERIMENTAL SETUP

The tests were conducted using a 2000 kN capacity hydraulic jack placing the specimen in the testing machine as shown in Fig. 3.1 & 3.2. The bearing surfaces of the testing machine and the bearing plates were wiped clean and any loose sand or other material removed from the surface of the specimen. Which were to be in contact with the bearing plates. The specimen was placed between the bearing plates in such a manner that the upper bearing plate was directly in line with the lower plate and the bearing plates extend at least 25 mm from each end of the specimen. The columns were placed restraining rotation at both ends. Care was taken to ensure that truly axial load was transformed to each of the columns. This was achieved by using plumb bob and a Theodolite.

3.1 INSTRUMENTS

Foil strain gauge (8mm x 8mm) 350 + 0.5 Ω were employed to measure the strains at the centre of the steel tube and centre of the reinforcement (core) of the specimens. Three numbers 50 mm dial test indicators with a least count of 0.01 mm one for axial and the other two for lateral were used to measure axial and lateral deformations upon loading as shown in Fig 3.2 Apart from these instruments plumb bob and linear scales have been used.

3.2 RESULTS AND DISCUSSION

Behaviour of the columns have been studied to understand deformation characteristics in the axial direction and in the transverse direction. Strains have been measured on the steel sheet in two perpendicular directions. Generally, the columns have shown linear behaviour up to about one third of the total load that is about 250 kN axial compressive load. It was envisaged to study the buckling characteristic because of the less width to length of column. But, none of the columns have shown buckling, near the mid portion of the column. The confinement of the column is so large and even the columns without the longitudinal reinforcement and L/D ratio of 25 have not shown any buckling. All the columns have failed near supports of column showing local buckling. Behaviour of each column and its characteristics has been explained in subsequent articles. Among various number of reinforcements, the ultimate load has been found to be maximum for L/D ratio of 15 to be in 4 number of reinforcements and in L/D ratio of 20 and 25 it is for 3 number of reinforcements for triangular fluted columns and the ultimate load has been found to be maximum for L/D ratio of 15, 20 and 25 to be in 4 number of reinforcements for rectangular fluted columns as shown in Fig.3.3(a) and Fig 3. 3(b) respectively.

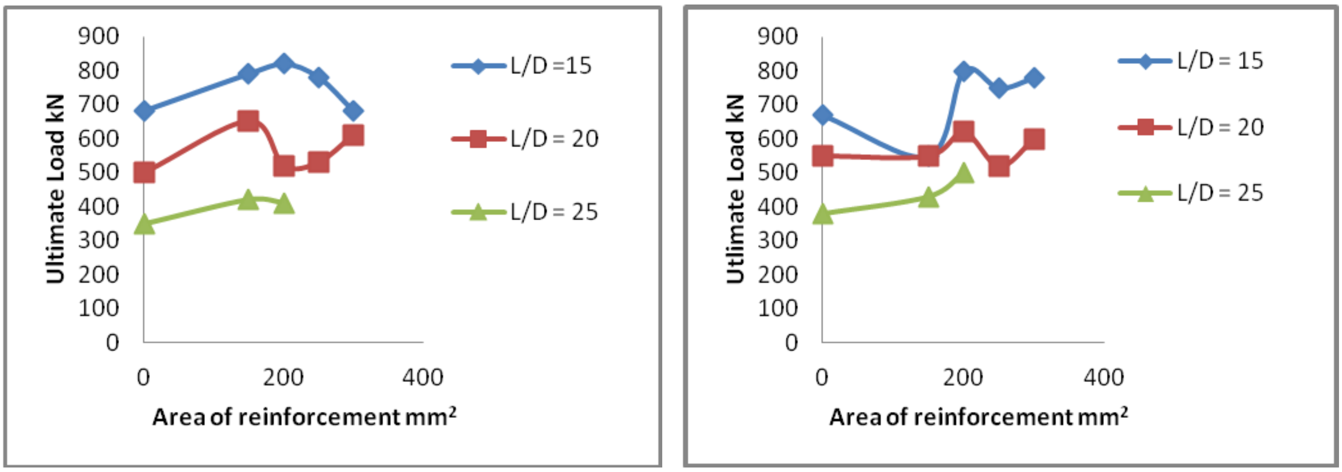

Fig 3.3(a) Triangular Fluted Column

Fig 3.3(b). Rectangular Fluted Column

Fig 3.3 Ultimate load v/s Area of reinforcement

3.3 EQUATIONS

Calculation of Equivalent Moment of Inertia for composite column

$I_e = I_c + I_{ess} + I_{est}$

Where I_e = Equivalent moment of inertia
I_c =Moment of inertia of concrete
I_{ess} = Equivalent moment of inertia of steel sheet
I_{est} = Equivalent moment of inertia of reinforcement

3.3.1 Rectangular Fluted Column

MI about x-x axis

$I_{xx} = I_{\text{circle}} + I_{\text{rectangle flute}}$

$$I_{xx} = \left(\frac{\pi\ (R^4 - r^4)}{4} + A\ \bar{y}^2\right) + \left(\frac{d\ b^3}{12} + A\ \bar{y}^2\right)$$

MI about y-y axis

$I_{yy} = I_{\text{circle}} + I_{\text{rectangle flute}}$

$$I_{yy} = \left(\frac{\pi\ (R^4 - r^4)}{4} + A\ \bar{x}^2\right) + \left(\frac{d\ b^3}{12} + A\ \bar{x}^2\right)$$

3.3.2 Triangular Fluted Column

MI about x-x axis

$I_{xx} = I_{\text{circle}} + I_{\text{triangle flute}}$

$$I_{xx} = \left(\frac{\pi\ r^4}{4} + A\,\bar{y}^2\right) + \left(\frac{b\ h^3}{36} + A\ \bar{y}^2\right)$$

MI about y-y axis

$I_{yy} = I_{\text{circle}} + I_{\text{triangle flute}}$

$$I_{yy} = \left(\frac{\pi \ r^4}{4} + A\,\bar{x}^2\right) + \left(\frac{h\,b^3}{36} + A\ \bar{x}^2\right)$$

3.4 Calculation of equivalent Area

$$A_t = A_c + m_1 A_{st} + m_2 A_{ss}$$

Where A_t = Area of transformed section
A_c = Area of concrete
A_{st} = Area of reinforcement steel
A_{ss} = Area of steel sheet

Modular ratio

$$m_1 = \frac{Est}{Ec}$$

$$m_2 = \frac{Ess}{Ec}$$

Where E_c = Young's Modulus of Concrete
E_{ss} = Young's Modulus of` Steel Sheet
E_{st} = Young's Modulus of reinforcement

I. FIGURES AND TABLES

No Reinforcement 3#8 4#8 5#8 6#8

Fig 2.2. Triangular fluted columns with and without reinforcement

No Reinforcement 3#8 4#8 5#8 6#8

Fig 2.3. Rectangular fluted columns with and without reinforcement

Fig 3.1 Experimental Setup

Fig.3.2 Dial Test Indicators laterally & axially

Table I. Details of testing of the materials from experimental results

SL No	Materials	Poission's ratio (μ)	Modulus of Elasticity (E) N/mm^2	Remarks
1	Concrete	0.16	0.223 x 10^5	Split tensile strength test
2	Reinforcement	0.28	0.21 x 10^5	Tensile test
3	Steel Sheet	0.26	0.723 x 10^5	Tension coupon test

Table II Comparison results of Equivalent Moment of Inertia of Fluted column, Non fluted internal diameter column and Non fluted external diameter column.

Sl No	Specimen	Equivalent Moment of Inertia mm^4 (with flutes)	Eq Moment of Inertia mm^4(without flutes considering internal dia)	Eq Moment of Inertia mm^4(without flutes considering external dia)	% increase (internal dia+with flutes)	% decrease (external dia – with flutes)
1	TFC-L/D 15	41.96 x 10^6	38.18 x 10^6	60.01 x 10^6	9.00	30.07
2	TFC-L/D 20	14.18 x 10^6	11.98 x 10^6	21.69 x 10^6	15.51	34.62
3	TFC-L/D 25	6.36 x 10^6	4.90 x 10^6	10.17x 10^6	22.95	37.46
4	RFC-L/D 15	46.23 x 10^6	38.18 x 10^6	60.01 x 10^6	17.41	22.96
5	RFC-L/D 20	16.76 x 10^6	11.98 x 10^6	21.69 x 10^6	28.52	22.72
6	RFC-L/D 25	8.15 x 10^6	4.90 x 10^6	10.17 x 10^6	39.87	19.86

Table III: Development Length of the Columns

Name of the Specimens	Development Length mm		% Increase
	Without Flutes(Internal Diameter)	With Flutes(Internal Diameter +Flutes)	
CFSFC-TFC-L/D 15	524.65	611.10	14.14
CFSFC-TFC-L/D 20	392.69	479.11	18.03
CFSFC-TFC-L/D 25	314.15	400.60	21.58
CFSFC-RFC-L/D 15	524.65	687.50	23.68
CFSFC-RFC-L/D 20	392.69	555.51	29.31
CFSFC-RFC-L/D 25	314.15	477.00	34.14

Table IV. Area of cross section of columns

Specimen Name Column-L/D-No Rein	A_t (Equivalent) mm^2 TFC	A_t (Equivalent) mm^2 RFC	% increases	Experimental Load kN		% increase
				TFC	RFC	
C-15-0	24338.14	25538.01	4.70	680	670	1.49
C-15-3	25776.68	26976.54	4.45	790	550*	43.63
C-15-4	26256.25	27456.12	4.37	820	800	2.50
C-15-5	26735.73	27935.60	4.30	780	750	4.00
C-15-6	27215.30	28415.17	4.22	680	780	12.82
C-20-0	14360.84	15560.71	7.71	500	550	9.09
C-20-3	15799.37	16999.24	7.06	650	550	18.18
C-20-4	16278.95	17478.82	6.86	520	620	16.12
C-20-5	16758.43	17958.30	6.86	530	520	1.92
C-20-6	17238.00	18437.87	6.51	610	600	1.66
C-25-0	9737.53	10937.39	10.92	350	380	7.89
C-25-3	11176.06	12375.92	9.70	420	430	2.32
C-25-4	11655.64	12855.50	9.33	410	500	18.00

* Without arc weld column. First experiment test specimen the sheet is opened up, immediately put arc weld for remaining columns, then the strength of the columns has been increases.

IV. CONCLUSION

- The moment of inertia gets increased by about 17%, 29% & 40% for RFC and 9%, 16% & 23% for TFC for L/D ratio of 15, 20 & 25 respectively.
- The development length i.e., width of the sheet of these triangular fluted columns increases for different L/D ratios of 15, 20 and 25 by 14%, 18% and 22% as compared to a circular column of the same diameter and the same for rectangular fluted columns will be 24%, 29% and 34%
- The cross section area gets increased by about 4.40%, 7% & 9.98% for L/D ratio of 15, 20 and 25 respectively for rectangular fluted columns as compared to triangular fluted columns.
- It is observed that the load resistance is better marginally in the case of rectangular fluted columns as compared to the triangular fluted columns by 1.31 %, 1.05 % and 9.92 % respectively for L/D ratio of 15, 20 and 25.
- Among various number of reinforcements, the ultimate load has been found to be maximum for L/D ratio of 15 to be in 4 number of reinforcements and in L/D ratio of 20 and 25 it is for 3 number of reinforcements for triangular fluted columns and the ultimate load has been found to be maximum for L/D ratio of 15, 20 and 25 to be in 4 number of reinforcements for rectangular fluted columns.
- The study has shown that for an L/D ratio 25, no buckling has been observed even without longitudinal reinforcement. All the columns failed by local buckling.

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