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Comparison of Experimental values with EC 4, ACI-318, AISC-LRFD of Concrete Filled Steel Fluted Columns for Concentric Load

Dr.B.R Niranjan[1] & Eramma.H[2]

[1]Professor, [2]Research Scholar , UVCE, Faculty of Engineering-Civil, Jnana Bharati Campus, Bangalore University, Bangalore: 560056, karnataka INDIA

Abstract: - The advantages of Concrete Filled Steel Tube (CFST) columns have proved its usefulness in the structural applications of the constructions. Though, application of CFST columns are gaining popularity, the analysis and design of these have not found a place in the codes of Bureau of Indian Standard Specifications. But, this has been incorporated in the codes of ACI 318. AISC - LRFD and EC 4 - Euro codal provisions. An attempt has been made here to check whether these equations can be made use for the analysis and design of Concrete Filled Steel Fluted Columns (CFSFC) also. It has been observed that by adopting EC 4, (Eurocode 4), for a Triangular Fluted Column (TFC), a discrepancy of about 47 percent has been observed. Whereas , ACI 318 and AISC -LRFD has shown about 48% and 64% respectively less compared to the experimental values. Similar results have been observed for Rectangular Fluted Columns (RFC).

Keywords: - *CFST, CFSFC, TFC, RFC, SCC*

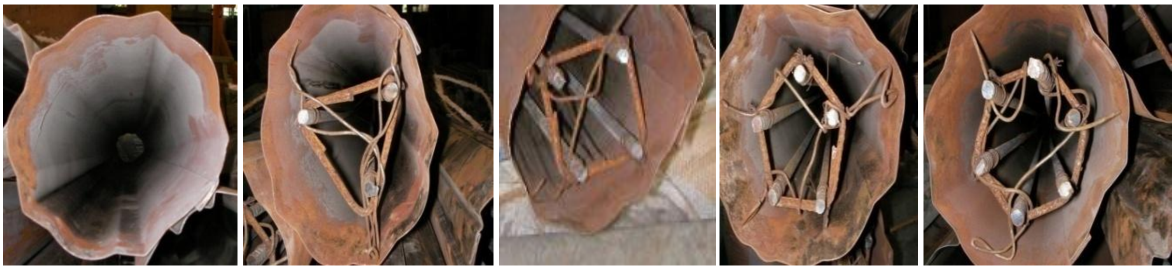
I. INTRODUCTION

Technology of concrete filled steel tubular column was evolved as early as 1970’s, itself, and there has been enough research carried out to understand the complete behaviour of these columns. CFST is a composite structural member, which resists the applied loads through the composite action of steel as well as concrete. The interactive and integral behaviour of concrete and structural steel elements makes it a cost effective alternative. In addition to its improved load carrying capacity, it is also aesthetically pleasing. With recent developments in the CFST columns beam column connections and advantage of fire resistant construction, architects have seized the opportunity to exploit the structural and aesthetic advantages of these columns in multistoried buildings. Since the steel confines concrete, the use of formwork can be discarded and the buckling strength increases . Due to the presence of concrete core, local buckling of steel tube is delayed and the strength deterioration after local buckling is moderated, both due to restraining effect of concrete. The strength of concrete is increased, due to the confining effect provided by steel tube and on other hand the strength deterioration is not that severe because concrete does not spall due to the confinement. Drying shrinkage and creep of concrete are much smaller in these columns as compared to other structural forms. Having listed all the advantages, however the major disadvantage of a composite column is the exposure of tube to the environmental effects (such as heat, cold, UV etc). For steel tubes, this raises concerns related to susceptibility to corrosion and fire safety. The structural properties of CFST columns include high strength, high ductility and high energy absorption capacity. The load carrying capacity and behaviour in compression, bending and shear are all superior to reinforced concrete. The reduction of the steel tube thickness in thin-walled CFST columns has the potential to significantly reduce construction costs. However, thin-wall CFST columns are susceptible to the local instability problem of thin-walled steel plates under compression and in-plane bending. The local buckling of steel tubes with geometric imperfections and residual stresses results in a reduction in the strength and ductility of members. Extensive research have been made for the past forty years in the field of concrete-filled steel tubular (CFST) columns, which are used as primary axial load carrying members in many structural applications including high rise buildings, bridges, piles and off shore structures. Researchers have carried out on plain CFST compression members, but no research has been carried out on fluted columns. The load carrying capacity and behaviour in compression, bending and shear are all superior to reinforced concrete. Currently there is no comprehensive design standard that can be used for the design of thin-walled CFST columns. Extensive research have been conducted on steel-concrete composite columns in which structural steel encases concrete.

The CFST fluted column is a structural member which resists the applied loads through the composite action of steel and concrete. However, the effect of confinement is required to be studied. Here a new approach of confining concrete by providing triangular and rectangular shaped fluting is being investigated by a well planned experimental work on concrete filled steel fluted columns. The parameter adopted for the study were (i) different shapes of fluted steel tubes. (ii) Different L/D ratio (iii) Without reinforcement and varying the number of reinforcements from 3 to 6 (iv) To obtain an appropriate method for the analysis and design of CFSFC among various codes. Results have been analyzed for M_{20} Self Compacting Concrete (SCC) specimens with respect to buckling characteristics, load deformations, stress strain characteristics and stiffness.

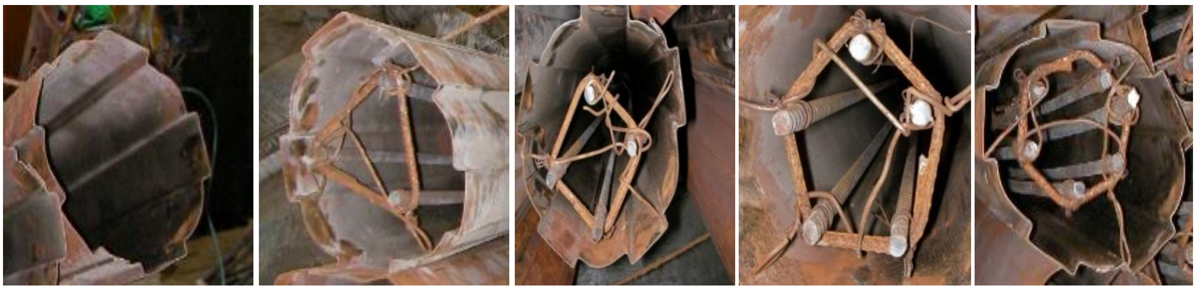
1.2 Experimental Setup:

The tests were conducted using a 2000 kN capacity hydraulic jack placing the specimen in the testing machine and geometry of the specimens are as shown in Fig. 1 to 3. 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 plates 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 on smooth plates at both ends. Care was taken to ensure that truly axial load was applied to each of the columns. Plumb bob and Theodolite has been employed to place the specimen truly vertical and hence load the specimen concentrically as shown in Fig. 4.



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

Fig1**. Triangular Fluted Steel Tube With and Without Reinforcement**



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

Fig 2. Rectangular Fluted Steel Tube With and Without Reinforcement

Fig.3.Experimental Setup

Fig. 4. Overall Experimental Setup with Theodolite

1.3 Experimental Programme

Thirteen concrete filled triangular fluted column test specimens with L/D= 15, 20, 25 and thirteen concrete filled rectangular fluted column test specimens with L/D = 15, 20, 25 were tested under concentric axial compression. All the columns were circular in shape provided with five triangular shaped and rectangular shaped fluting running the length of the column. The steel fluted core was obtained by pressing a plane mild steel sheet at 5 different locations in triangular shape and rectangular shape. The resulting section was then closed by using tack and arc welding, which was continuous throughout the length of the column. All the specimen were 2500 mm tall and 0.8 mm thick In all columns were designed by using self compacting concrete M_{20} grade of concrete. Test was conducted in a loading frame of capacity 100 tones, using a hydraulic jack of capacity 2000 kN with an accuracy of 10 kN. Initial seating of load of 50 kN was applied and all the temporary supports were removed. The alignment of the column was Faculty of Engineering-Civil verified at the same time. At the outset , the increase in axial deformation with the increase in load was found to be marginal. The columns were placed restraining rotation at both ends and the loads were applied without shock at an increment of 50 kN until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained. Special attention was given to verifying the correct position of the column, before any loading. After completing the initial set up the specimen were placed on the loading jacked to fix the specimen between two supports. Care was taken to maintain vertically along both vertical plane and line of action of load and loading axis . The maximum load and load applied to the specimen was then recorded and the appearance of the concrete and any unusual features in the type of failure noted. For details refer Tables 1 & 2.

Table. 1. Total Number of Specimens For Triangular Fluted Columns

Sl No	Name of the Specimen	Mean Diameter	Thickness of Steel Tube	L/D ratio	Length of Column
1	CFSFC-TFC-NR-D167	167	0.8	15	2500
2	CFSFC-TFC-3/#8-D167	167	0.8	15	2500
3	CFSFC-TFC-4/#8-D167	167	0.8	15	2500
4	CFSFC-TFC-5/#8-D167	167	0.8	15	2500
5	CFSFC-TFC-6/#8-D167	167	0.8	15	2500
6	CFSFC-TFC-NR-D125	125	0.8	20	2500
7	CFSFC-TFC-3/#8-D125	125	0.8	20	2500
8	CFSFC-TFC-4/#8-D125	125	0.8	20	2500
9	CFSFC-TFC-5/#8-D125	125	0.8	20	2500
10	CFSFC-TFC-6/#8-D125	125	0.8	20	2500
11	CFSFC-TFC-NR-D100	100	0.8	25	2500
12	CFSFC-TFC-3/#8-D100	100	0.8	25	2500
13	CFSFC-TFC-4/#8-D100	100	0.8	25	2500

Table 2. Total Number of Specimens For Rectangular Fluted Columns

Sl No	Name of the Specimen	Mean Diameter	Thickness of Steel Tube	L/D ratio	Length of Column
1	CFSFC-RFC-NR-D167	167	0.8	15	2500
2	CFSFC-RFC-3/#8-D167	167	0.8	15	2500
3	CFSFC-RFC-4/#8-D167	167	0.8	15	2500
4	CFSFC-RFC-5/#8-D167	167	0.8	15	2500
5	CFSFC-RFC-6/#8-D167	167	0.8	15	2500
6	CFSFC-RFC-NR-D125	125	0.8	20	2500
7	CFSFC-RFC-3/#8-D125	125	0.8	20	2500
8	CFSFC-RFC-4/#8-D125	125	0.8	20	2500
9	CFSFC-RFC-5/#8-D125	125	0.8	20	2500
10	CFSFC-RFC-6/#8-D125	125	0.8	20	2500
11	CFSFC-RFC-NR-D100	100	0.8	25	2500
12	CFSFC-RFC-3/#8-D100	100	0.8	25	2500
13	CFSFC-RFC-4/#8-D100	100	0.8	25	2500

Where CFSFC - Concrete Filled Steel Fluted Column , NR - No reinforcement
TFC - Triangular Flute Column , 3/#8 - 3 bars of 8 mm diameter of reinforcement
RFC - Rectangular Flute Column , 4/#8 - 4 bars of 8 mm diameter of reinforcement
D167- Diameter of the column 167 mm, 5/#8 - 5 bars of 8 mm diameter of reinforcement
D125- Diameter of the column 125 mm, 6/#8 - 6 bars of 8 mm diameter of reinforcement
D100- Diameter of the column 100 mm.

II. STANDARD SPECIFICATION:

2.1 EC 4 - Euro Code

Eurocode utilizes Squash (Plastic) resistance method of analysis developed by Gerald Newman. It is the opinion of the researchers that results of the Eurocode compares well with the result of experiments that they have conducted. The EC4- Eurocode adopts Plastic Resistance concept in analysing the CFST columns. The plastic resistance method makes use of concrete filled circular hollow sections exhibit enhanced resistance due to the triaxial containment effect. Though it is said that this method is not applicable for the composite columns failing by local buckling, it has been a practice to check the load resisted by the columns. It is a practice to design the structural elements by the ultimate limit state. For structural adequacy, the internal forces and moments resulting from the most unfavourable load combination should not exceed the design resistances of the composite cross-sections. While local buckling of the steel sections may be eliminated, the reduction in the compression resistance of the composite column due to overall buckling should be allowed for, together with the effects of residual stresses and initial imperfections. Moreover, the second order effects in slender columns, as well as the effect of creep and shrinkage of concrete under long-term loading, must be considered if they are significant.

2.1.1 EC 4 Specimen Calculation (CFSFC-RFC-3#8-D167)

Details of the section

External diameter , D=187 mm
Internal diameter, d = 167 mm
Thickness of steel casing , t = 0.8 mm
Nominal grade of concrete , f_{ck} = 20 N/mm^2
Nominal grade of steel (Reinforcement), f_{yst} = 421.29 N/mm^2
Nominal grade of steel sheet, f_{yss} = 144.61 N/mm^2
Height of the column L = 2500 mm

Material Properties

Partial factor for concrete γ_c = 1.5
Partial safety factor for steel γ_s = 1.15
Design compressive strength of concrete

$$f_{cd} = \frac{f_{ck}}{\gamma_c}$$
$$= 20 / 1.5 = 13.33 \text{ N/mm}^2$$

Design compressive strength of steel (Reinforcement)

$$f_{yd} = \frac{f_y}{\gamma_s}$$
$$= 421.29 / 1.15 = 366.33 \text{ N/mm}^2$$

Design compressive strength of steel (Reinforcement)

$f_{sdss} = \frac{f_y}{\gamma_s}$

$= 144.61 / 1.15 = 125.74\ N/mm^2$

Section Properties

Area of concrete

$A_c = \{ \left(\frac{\pi (d)^2}{4}\right) + 5\ (l \times h)\}$

$= [(\pi \times (167)^2)/4] + 5\ (40 \times 10)$

$= 23903.96\ mm^2$

Area of steel sheet

$A_{ss} = A_2 = \{(2\pi r - 5xl) + 10xh + (5xL)\}x\ t$

$= \{(2x\pi \times 83.5 - 5x\ 40) + (10x\ 10) + (5x40)\}x\ 0.8$

$= 499.71\ mm^2$

Area of steel (reinforcement)

$A_{st} = A_s = \frac{\pi (d)^2}{4} \times n$

$= \pi (8)^2 / 4 \times 3$

$= 150.79\ mm^2$

Moment of Inertia of concrete

$Ic = 46 \times 10^6\ mm^4$

Moment of Inertia of steel sheet

$Iss = 0.01445 \times 10^6\ mm^4$

Moment of Inertia of reinforcement

$Ic = 0.024439203 = 24.43 \times 10^{-3}\ mm^4$

Elastic Flexural Stiffness

Modulus of Elasticity of Steel

$E_{ss} = 0.72 \times 10^5\ N/mm^2$

$E_{st} = 2.1 \times 10^5\ N/mm^2$

Safety factor for stiffness $\gamma_{ce} = 1.35$

Correction factor $k_e = 0.8$

$E_{cm} = 9500(f_{ck} + 0.8)^{1/3}$

$= 9500\ (20 + 0.8)^{1/3}$

$= 26126.30\ N/mm^2 = 26127\ N/mm^2$

Ratio of Secant modulus to safety factor

$E_{cd} = \frac{E_{cm}}{\gamma_{ce}}$

$= 26127/1.35$

$= 19352.82\ N/mm^2 \approx 19353\ N/mm^2$

The plastic resistance of a concrete filled circular hollow section may be obtained as follows

$N_{pl,Rd} = A_2\, \eta_2 f_{yd} + A_s f_{sd} + A_c f_{cd}\left[1 + \eta_1\, \frac{t}{d}\frac{f_y}{f_{ck}}\right]$

Where t is the wall thickness of the steel hollow section in mm

$\left.\begin{array}{l} \eta_1 = \eta_{10}\left(1 - \frac{10e}{d}\right) \\ \eta_2 = \eta_{20} + (1 - \eta_{20})\frac{10e}{d} \end{array}\right\}$ for $0 < e \leq \frac{d}{10}$

$\left.\begin{array}{l} \eta_1 = 0 \\ \eta_2 = 1.0 \end{array}\right\}$ for $e > \frac{d}{10}$

The basic values η_{10} and η_{20} depend on the non- dimensional slenderness ratio λ and are defined as follows

$\eta_{10} = 4.9 - 18.5\,\lambda + 17\lambda^2$ but $\eta_{10} \geq 0$

$\eta_{20} = 0.25\ (3 + 2\lambda)$ but $\eta_{20} \leq 0$

λ exceeds the value 0.5

$\eta_{10} = 0$

$\eta_{20} = 1.0$

Flexural Stiffness

$(EI)_e = E_2\, I_2 + E_s\, I_s + 0.6\, E_{cm}\, I_c$

$= 0.72 \times 10^5 \times 0.01445 \times 10^6 + 2.1 \times 10^5 \times 24.43 \times 10^{-3} + 0.6 \times 26127 \times 46.23 \times 10^6$

$= 7.26 \times 10^{11}$ N- mm^2

$\lambda = \sqrt{\frac{N_{pl,Rd}}{N_{cr}}}$

$= \sqrt{(436712.21 / 1146060.25)}$

$= 0.61$

If $\lambda > 0.5$ so select

$\eta_{10} = 0$

$\eta_{20} = 1.0$

$N_{cr} = \frac{\pi^2 (EI)_e}{l^2}$

$= \pi^2 \times 7.26 \times 10^{11} / (2500)^2$

$= 1146060.25$ N

$N_{pl,Rd} = A_2\, \eta_2 f_{yd} + A_s f_{sd} + A_c f_{cd}\left[1 + \eta_1 \frac{t}{d} \frac{f_y}{f_{ck}}\right]$

$= 499.71 \times 1.0 \times 125.74 + 150.79 \times 366.33 +$
$23903.96 \times 13.33\, [1 + 0 \times (0.8/167) \times (421.29/20)]$

$= 436712.21$ N

$= 436.71$ kN ≈ 437 kN.

2.1.2 ACI- 318

The composite concrete and steel structural system combines the rigidity and formability of reinforced concrete with the strength of structural steel to produce an economic structure. For concrete-encased composite structural members, an additional advantage is that the concrete used for encasing a structural steel not only increases its stiffness, but also protects it from fire damage and local buckling failure.In the United States, specific regulations for the design of concrete-encased composite columns are included in two different sets of structural design specifications. One is the building code for structural concrete of the American Concrete Institute (ACI) , and the other is the specification of Load and Resistance Factor Design (LRFD) published by American Institute of Steel Construction (AISC). The ACI-318 provisions(1999) for the design of the encased composite columns follow the same procedure as that for the reinforced concrete columns. In contrast, the AISC-LRFD provisions (1993) are based on analogous to the steel column design. Both ACI and AISC design provisions are applied to concrete-encased structural steel columns and to concrete-filled pipes or tubing.The AISC-LRFD rules specifically require at least 4% steel ratio of the composite section comprised of structural steel. However, the ACI rules have no such limitation on steel ratio. In addition, the former is recommended for the symmetric composite section, but the latter is recommended for both symmetric and unsymmetrical sections. It is noted that the above-mentioned specifications often give significantly different values of calculated ultimate strengths.The objective here is to investigate the differences between the ACI and the AISC approaches for the design of concrete-encased composite columns and to evaluate how well they experimental the actual column behaviour through a series of statistical comparisons. The studies are made to compare the predicted strengths by using the ACI and the AISC approaches.

In the US, the ACI building code had been the sole major reference for the design of composite columns until the publication of the AISC-LRFD specification in 1986. The following sections briefly introduce the concerned strength provisions for the concrete-encased composite columns as recommended in section 10.16 of the ACI-318 building code (1999),

2.1.2.1 Axial compressive strength

Under uniaxial compression, the nominal compressive strength, P_u of a concrete-encased composite column can be found by summing up the axial-load capacities of the materials that make up the cross section. This leads to

$P_n = 0.8\, P_o$

$P_o = 0.85\, f_c'\, A_c + F_{yr}\, A_r + F_y\, A_s$

Where

P_o = Column capacity under uniaxial compression

f_c' = Compressive strength of concrete

A_c = Area of concrete

F_{yr} = Yield strength of longitudinal reinforcement

A_r = Area of longitudinal reinforcement

F_y = Yield strength of steel shape
A_s = Area of steel shape

The nominal axial compressive strength P_n for an encased composite column is limited to 0.8 P_o owing to a minimum eccentricity under axial load for all designed columns.

2.1.2.2 ACI-318 Specimen Calculation (CFSFC-RFC-3#8-D167)

$P_o = 0.85\, f_c'\, A_c + F_{yr}\, A_r + F_y\, A_s$
$= 0.85 \times 20 \times 23903.96 + 421.29 \times 150.79 + 144.61 \times 499.71$
$= 542156.69$ N≈ 542.15 kN
$P_n = 0.8 \times 542.29$
$= 433.72$ kN ≈ 434 kN

2.1.3 AISC-LRFD

Although the AISC specification has included design provisions for composite beams with shear connectors since 1961, the design requirements for composite columns were not recommended until the publication of the first edition of the AISC-LRFD specification in 1986. The concept of extending the steel column design methodology to the composite columns using the modified properties was first introduced by **Furlong**[(1)]. Modified yield stress F_{my}, modulus of elasticity E_m and radius of gyration γ_m were incorporated into steel column design equations for the design of composite columns. This procedure was presented by the Task Group 20 of the Structural Stability Research Council (SSRC) in 1979. The following sections briefly introduce the concerned strength provisions for encased composite columns as recommended in section 7.4 of the AISC-LRFD specification (1993).

2.1.3.1 Axial Compressive Strength

The capacity of an encased column is determined from the same equations as that for bare steel columns except the formulas being entered with modified properties F_{my}, E_m and γ_m The nominal axial compressive strength of an encased composite column is

$P_n = A_s\, F_{cr}$

Where As is the area of the steel shape and F_{cr} is the critical stress of the column given by the following equations

$F_{cr} = (0.685^{\lambda_c^2})\, F_{my}$ for $\lambda_c \leq 1.5$ and

$F_{cr} = \left(\frac{0.877}{\gamma_c^2}\right) F_{my}$ for $\lambda_c > 1.5$

Where

$$\lambda_c = \left(\frac{KL}{\pi\, \gamma_m}\right)\sqrt{\frac{F_{my}}{E_m}}$$

F_{my} = Modified yield stress
γ_m = Modified radius of gyration
E_m = Modified modulus of elasticity.

The modified properties F_{my}, E_m and γ_m account for the contribution of concrete and rebars in the composite section. The modified values F_{my} and E_m can be determined by the following equations

$$F_{my} = F_y + C_1\, F_{cr}\frac{A_r}{A_s} + C2\, f_c\frac{A_c}{A_s}$$

$$E_m = E_s + C_3\, E_c\frac{A_c}{A_s}$$

Where C_1, C_2, C_3 = Numerical coefficients, for encased composite columns
$C_1 = 0.7$, $C_2 = 0.6$ and $C_3 = 0.2$.

2.1.3.2 AISC-LRFD Specimen Calculation (CFSFC-RFC-3#8-D167)

$F_{my} = F_y + C_1\, F_{cr}\frac{A_r}{A_s} + C2\, f_c\frac{A_c}{A_s}$
$= 421.29 + 0.7 \times 144.61 \times (150/499.71) + 0.6 \times 20 \times (23903.96/499.71)$
$= 1025.85$ N/mm^2

$E_m = E_s + C_3\, E_c\frac{A_c}{A_s}$
$= 2.1 \times 10^5 + 0.2 \times (0.22 \times 10^5) \times (23903.96 / 499.71)$
$= 420476.92$ N/mm^2

$$\gamma_m = \sqrt{\frac{I_e}{A}}$$

$$= \sqrt{\frac{46.23\, X\, 10^6}{26976.54}}$$

$= 41.39\ mm^2$

$$\lambda_c = \left(\frac{KL}{\pi\, \gamma_m}\right)\sqrt{\frac{F_{my}}{E_m}}$$

$$= \left(\frac{1\ x\ 2500}{\pi\ x\ 41.39}\right)\sqrt{\frac{1025.85}{420476.92}}$$

$= 0.949 \approx 0.95$

$\lambda_c < 1.5$

Choose for critical stress of the column

$F_{cr} = (0.685^{\lambda_c^2})\, F_{my}$

$= (0.685^{(0.95)^{\wedge}2})\ x\ 1025.85$

$= (0.685^{(0.9025)})\ x\ 1025.85 = 703.12\ N/mm^2$

Axial Compressive Strength

$P_n = A_s\, Fcr$

$= 499.71\ x\ 703.12$

$= 351356.09\ N$

$= 351.35\ kN \approx 352\ kN$

The results have been tabulated in Table 3 to 6

Table 3: Results of Experiment and calculation according to EC4, ACI-318 and AISC-LRFD for Triangular Fluted Columns

*Note: 15 C 0 refers to Column with L/D ratio of 15 having no reinforcements

Sl No	Name of the Specimen *	Expt Load kN	Euro Code 4		ACI-318		AISC-LRFD	
			Load kN	% decrease	Load kN	% decrease	Load kN	% decrease
1	15C0	680	361	46.91	362	46.76	363	46.61
2	15C3	790	416	47.34	413	47.72	362	54.17
3	15C4	820	434	47.07	430	47.56	362	55.85
4	15C5	780	453	41.92	447	42.69	361	53.71
5	15C6	680	471	30.73	464	31.76	361	46.91
6	20C0	500	219	56.20	219	56.20	180	64.00
7	20C3	650	274	57.84	270	58.46	181	72.15
8	20C4	520	293	43.65	287	44.80	177	65.96
9	20C5	530	311	41.32	304	42.64	174	67.16
10	20C6	610	329	46.06	321	47.37	171	71.96
11	25C0	350	152	56.57	152	56.57	106	69.71
12	25C3	420	207	50.71	203	51.66	92	78.09
13	25C4	410	226	44.87	220	46.34	87	78.78

15 C 3 refers to Column with L/D ratio of 15 having 3 number of reinforcement and so on....

Table 4: Results of Experiment and calculations according to EC4, ACI-318 and AISC-LRFD for Rectangular Fluted Columns

Sl No	Name of the Specimen*	Expt Load kN	Euro Code 4		ACI-318		AISC-LRFD	
			Load kN	% decrease	Load kN	% decrease	Load kN	% decrease
1	15C0	670	382	42.98	383	42.83	352	47.46
2	15C3	550*	437	20.54	434	21.09	352	36.00
3	15C4	800	455	43.12	451	43.62	351	56.12
4	15C5	750	474	36.80	468	37.60	351	53.20
5	15C6	780	492	36.92	485	37.82	351	55.00
6	20C0	550	240	56.36	240	56.36	191	65.27
7	20C3	550	295	46.36	291	47.09	184	66.54
8	20C4	620	314	49.35	308	50.32	181	70.80
9	20C5	520	332	36.15	325	37.50	179	65.57
10	20C6	600	350	41.66	342	43.00	176	70.66
11	25C0	380	173	54.47	173	54.43	114	70.00
12	25C3	430	228	46.97	223	48.13	103	76.04
13	25C4	430	247	50.60	240	52.00	99	80.20

Table 5. Triangular Fluted Column Results of EC4 with ACI-318, EC4 with AISC-LRFD & ACI-318 with AISC-LRFD

Sl No	Name of the specimen*	EC4 Load kN	ACI-318 Load kN	AISC-LRFD Load kN	EC4-ACI-318 %increase	EC4-(AISC-LRFD) %increase	ACI-318-AISC-LRFD %increase
1	15C0	361	362	363	-0.27	-0.55	-0.27
2	15C3	416	413	362	0.72	12.98	12.34
3	15C4	434	430	362	0.92	16.58	15.81
4	15C5	453	447	361	1.32	20.30	19.23
5	15C6	471	464	361	1.48	23.35	22.19
6	20C0	219	219	180	0	17.80	17.80
7	20C3	274	270	181	1.45	33.94	32.96
8	20C4	293	287	177	2.04	39.59	38.32
9	20C5	311	304	174	2.25	44.05	42.76
10	20C6	329	321	171	2.43	48.02	46.72
11	25C0	152	152	106	0	30.26	30.26
12	25C3	207	203	92	1.93	55.55	54.67
13	25C4	226	220	87	2.65	61.50	60.45

Table 6. Rectangular Fluted Column Results of EC4 with ACI-318, EC4 with AISC-LRFD & ACI-318 with AISC-LRFD

Sl No	Name of the Specimen*	EC4 Load kN	ACI-318 Load kN	AISC-LRFD Load kN	EC4-ACI-318 %increase	EC4-(AISC-LRFD) %increase	ACI-318-AISC-LRFD %increase
1	15C0	382	383	352	-0.26	7.85	8.09
2	15C3	437	434	352	0.68	19.45	18.89
3	15C4	455	451	351	0.87	22.85	22.17
4	15C5	474	468	351	1.26	25.94	25
5	15C6	492	485	351	1.42	28.65	27.62
6	20C0	240	240	191	0	20.41	20.41
7	20C3	295	291	184	1.35	37.62	36.76
8	20C4	314	308	181	1.91	42.35	41.23
9	20C5	332	325	179	2.10	46.08	44.92
10	20C6	350	342	176	2.28	49.71	48.53
11	25C0	173	173	114	0	34.10	34.10
12	25C3	228	223	103	2.19	54.82	53.81
13	25C4	247	240	99	2.83	59.91	58.75

III. CONCLUSION

a. Triangular Fluted Columns

- Eurocode 4, ACI-318 and AISC-LRFD equations compare well each other and the loads calculated using these codes are about 42, 43 and 51% conservative on an average as compared to that of experimental results for triangular fluted columns with L/D ratio of 15, only. Similarly these values are 49, 50 and 68% for L/D ratio of 20 and 50, 51 and 75% for L/D ratio of 25.
- EC4 with ACI-318 , EC4 with AISC-LRFD and ACI-318 with ASIC-LRFD are about 0.84, 14.53 & 13.86% for L/D ratio 15, 1.63, 36.68 & 35.71% for L/D ratio 20, 1.52 , 49.10 & 48.46% for L/D ratio 25 conservative on an average as compared to that of codes results for triangular fluted columns.

b. Rectangular Fluted Columns

- Eurocode 4, ACI-318 and AISC-LRFD equations compare well each other and the loads calculated using these codes are about 36, 37 and 50% conservative on an average as compared to that of experimental results for rectangular fluted columns with L/D ratio of 15, only. Similarly these values are 46, 47 and 68% for L/D ratio of 20 and 50, 51 and 75% for L/D ratio of 25.

- EC4 with ACI-318 , EC4 with AISC-LRFD and ACI-318 with ASIC-LRFD are about 0.79, 20.95 & 20.35% for L/D ratio 15, 1.52, 39.23 & 38.37 % for L/D ratio 20, 1.67 , 49.61 & 48.88% for L/D ratio 25 conservative on an average as compared to that of codes results for rectangular fluted columns.

- Comparison of the results of the three codes with experimental results revealed that Eurocode-4 and ACI-318 compare well each other and are about 55% and 45% that of experimental results for triangular fluted columns whereas AISC-LRFD yields about 35% of values of experimental results. The equations provided in the three codes cannot be used as it is and requires modification.

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