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Strength Aspects of Concrete Filled Steel Tube Columns Through Design Codes

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Abstract:

Concrete filled steel tabular columns have increased huge significance in recent decades due to various structural benefits particularly in developed countries like china, Japan, U.S.A, Britain. In this paper analytical equations are put to understand the mechanism of concrete filled steel tube columns under axial loading for both greased and non-greased columns. For this purpose a comparison between designs codes such as Eurocode-4, ACI, AS, AISC-LRFD and CECS 28:90 has been made in evaluating the axial compressive strength of concrete filled steel tube columns. Eurocode-4 and CECS 28:90 incorporate confinement effect of concrete because of steel tube in evaluating the axial compressive strength of CFST columns. In Eurocode-4 the confinement effect is related to slenderness ratio (λ) and eccentricity (e) of the applied loading. In CECS 28:90 slenderness ratio and load eccentricity are taken as independent parameters governing the ultimate strength of concrete filled steel tube columns.

Keywords: Concrete filled steel tube column, axial load capacity and design codes

I. INTRODUCTION

Concrete filled steel tube columns (CFST) consist of a steel tube filled with concrete. The steel in the concrete filled steel tube (CFST) column acts both as longitudinal as well as lateral reinforcement. Because of which steel is exposed to biaxial worry of longitudinal pressure and circle strain. All the while concrete is focused on tri-pivotally. What's more, the area of the steel and the solid in the cross segment upgrades the quality and solidness of the segment. In concrete filled steel tube (CFST) sections, steel lies at the peripheral border where it performs most effectively in pressure and in opposing bowing minute. Also the solidness of the solid filled steel tube section is significantly improved in light of the fact that the steel is found most remote from the centroid, where it makes top level augmentation to the snapshot of latency. Because of the advantage of the composite activity of the two materials CFST sections give incredible seismic occasion safe properties and other basic properties like high quality, high pliability and huge vitality assimilation limit. The collaboration of the steel tube with the solid likewise forestalls the neighborhood clasping of the steel tube, because of the limiting impact of cement. The quality of cement is expanded because of the constrainment impact gave by the steel tube bringing about less quality decrease, as concrete spading is forestalled by the steel tube. Due to the high seismic presentation, the solid filled steel forbidden (CFST) segments are turning out to be increasingly more well known lately. As indicated by the past research on concrete filled steel forbidden (CFST) segments by different researchers on the concentric conduct of cement filled steel unthinkable segments, a definitive hub quality of solid filler steel forbidden segment is influenced by the cross area and thickness of steel tube. Other than solid filler forbidden sections have

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numerous points of interest over customary fortified solid segments which make them more grounded and prudent also. In solid filler unthinkable sections the steel proportion is constantly higher in this manner giving greater malleability to the structure. The use of structure work is totally spared bringing about quicker and practical development with less labor.

One of the noteworthy parameters is the bond impact. Taking into account the mechanical properties of the high quality cement, for instance, Poisson proportion and the proportion of shrinkage vary from the low or medium quality cement, the bond quality between the steel tube and the solid center is essential on the hub load limit with regards to excellent cement filled steel tube sections. Different investigations have been finished by the past examiners to investigate the bond impact of CFST sections. The conduct of the solid filled unthinkable segments is affected by the width-to-thickness D/t extent, slimness proportion L/D and pivotal burden, right now precision of exploratory outcomes is contrasted and configuration codes.

1. Experimental Investigation

A total of 12 circular concrete filled steel tube specimens were cast and tested under axial loading. Out of 12 CFST specimens, 6 specimens were greased inside of outer steel tube and other 6 specimens were kept ungreased inside the outer steel tube to give an interaction between the outer steel tube and inner concrete core. The test was performed to explore the bond effect on the axial load capacity of circular concrete filled steel tube columns. The thickness of the steel tubes was kept 4 mm and 5 mm. The geometry of CFST columns are listed in Table 1. The D/t ratio of concrete filled steel tube columns varied from 20 to 37.5 and L/D ratio varied from 4 to 6.

2.1 **Materials properties**

Various properties of steel used for the outer tubes were found by performing tensile tests on specimens made out of it. Three such specimens were cut from each steel tube with an external diameter of 100 mm, 125 mm and 150 mm, and having thickness of 4 and 5 mm. It was observed that the average yield stresses (f_y) of the steel specimens were 288 MPa, 380 MPa and 440 MPa respectively. For the determination of concrete compressive strength, three concrete cube specimens of size 150 mm × 150 mm × 150 mm were cast as shown in Fig. 1. It was observed that the average compressive strength (f_{cu}) of cube was 36.7 N/mm^2 at 28 days. The same grade of concrete as used for casting specimens was utilized for filling the core of CFST columns.

Fig. 1 Concrete cube specimens

Table 1: Geometric of circular concrete filled steel tube columns

Specimens	Outer diameter, D (mm)	Thickness of steel, t (mm)	Height, L (mm)	D/T	L/D	Area (mm^2)		
						Steel (As)	Concrete (Ac)	Total

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C1T4	100	4	600	25.0	6.0	1206	7235	8441
C1T5	100	5	600	20.0	6.0	1492	7085	8577
C2T4	125	4	600	31.3	4.8	1521	11493	13014
C2T5	125	5	600	25.0	4.8	1885	11304	13189
C3T4	150	4	600	37.5	4.0	1835	16733	18568
C3T5	150	5	600	30.0	4.0	2278	16504	18782

2.2 Test specimens

To check the behavior of greased and non-greased CFST columns under axial loading, composite columns with the outer steel tube diameter of 100 mm, 125 mm and 150 mm having a thickness of 4 and 5 mm were cast. The height of all specimens was kept constant as 600 mm. The casting of specimens was done in five layers, with each layer compacted by using vibrator. The top surfaces of the CFST members were leveled after pouring of concrete to make a plane surface for loading. The top surface of each specimen was closed with a plastic sheet for 24 hours as shown in Fig. 2, which was replaced the next day with wet burlap, and it was kept on the specimens for 28 days, with water being sprinkled on it each day. The geometry of the specimens is listed in Table 1. CFST columns after casting are shown in Fig. 3.

Fig. 2 Circular concrete filled steel tube columns closed with a plastic sheet

Fig. 3 Circular concrete filled steel tube columnsclosed with wet burlap for curing

I.

3. Strength Comparison byDesign Codes

II.

3.1 Eurocode-4

III.

Eucocode-4 is the most recently developed, internationally acclaimed guidelines adopted for design of composite columns. The design theory proposed by the code is based on the rigid plastic method of analysis which assumes fully yielded steel and fully crushed concrete. The code uses a column curve to determine the effect of slenderness in concrete filled steel tube columns. In Eurocode-4, the confinement effect is related to slenderness ratio

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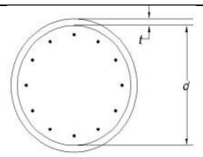
($\bar{\lambda}$) and eccentricity (***e***) of the applied loading. Eurocode-4 includesdesign mechanism for both concrete encased and steel filled tabular columns. Eurocode-4 gives ultimate axial force equations for circular concrete filled steel tube columns. To check local buckling of CFST columns limiting values of the specimens are governed by the equations given in Table 2.

Table 2: Limiting value of CFST column

Crosssection	**Shape**	**Max(d/t) and Max (b/t)**
Circular hollow steel section		$\frac{d}{t} < 90\frac{235}{f_y}$

The ultimate axial strength of the concrete filled tabular column is given by

$N_c = A_s f_y + A_c f_{ck}$

For circular sections, Eurocode 4 considers confinement effect provided relative slenderness ($\bar{\lambda}$)hasvaluelessthan0.5and(***e***/d)<0.1.Relativeslenderness ($\bar{\lambda}$) is definedas

$\bar{\lambda} = \sqrt{\frac{N_c}{N_{cr}}}$

$N_{cr}$is defined as the Euler buckling strength of the composite column, mathematically given by

$N_{cr} = \frac{\pi^2 \,(EI_{eff})}{l^2}$

Further,

$EI_{eff} = E_s I_s + 0.81 E_{cm} I_c$

Where 0.81 is an empirical multiplier and $E_{cm}$is the secant modules of concrete. To consider the effect of long term elastic flexural stiffness, we have

$E_{eff} = \frac{E_{cm}}{y_c}$

Where y_c is the safety factor equal to 1.35

$EI_{eff} = E_s I_s + 0.6 E_{cm} I_c$

So the ultimate load carrying capacity of a circular concrete filled tabular column is calculated by

$N_c = \eta_2 A_s f_y + A_c f_{ck}\left(1 + \eta_1 \frac{t f_y}{d f_{ck}}\right)$

Where $\eta_1$and $\eta_2$are the factors considering the confinement effect, for members without eccentricity

$\eta_1 = \eta_{10}$and$\eta_2 = \eta_{20}$

Confinement effect are determined by relative slenderness as

$\eta_1 = 4.9 – 18.5\bar{\lambda} + 17\bar{\lambda}^2$

$\eta_2 = 0.25(3 + 2\bar{\lambda})$

$\chi$is termed as column resistance reduction factor used to diminish the value of compressive resistance of a composite column.

$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}}$

Where ϕ is a parameter depending up on the internal reinforcing bars.

$\phi = 0.5\left[1 + 0.21(\bar{\lambda} - 0.2)\bar{\lambda}^2\right]$

3.2 AISC– LRFD

Code proposes design mechanism for composite structures. According to the LRFD design mechanismitbelievesthatcompositematerialsina composite structure should act together to resist bendingorinotherwordsasonei.e.monolithically.

LRFD code takes confinement effect of concrete into consideration by increasing strength reduction factor from 0.85 to 0.95 in case of circular CFST columns. The code furthersuggeststhe minimum steel required shall be more than 4% in composite elements.

$\rho_{Sr} > 4\%$

To resist local buckling of steel tubes, the thickness of the steel tubes are governed by the equations

$\frac{D}{t} = 0.15\frac{E}{f_y} for circular CF$ST column

The ultimate load carrying capacity of circular CFST is given by

$P_n = A_s f_y + \phi A_c f_{ck}$

For circular CFST column

$P_n = A_s f_y + 0.85 A_c f_{ck}$

Compressive strength reduction factor has been increased from 0.85 to 0.95 in case of circular CFST to incorporate the effect of concrete confinement.

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3.3 ACI– LRFD and Australian Standard

The American Concrete Institute and American Standard codes use the similar formula for evaluation the axial compressive load. The ACI (1995) and AS (1994) codes do not consider the effect of concrete confinement. The limiting thickness of steel tube to prevent local buckling depends on achieving the yield stress in a hollow steel tube under monotonic axial loading, which is not a necessary requirement for concrete filled steel tube columns. The failure load in concrete filled steel tube columns is calculated by using equation

$$N_c = A_s f_y + 0.85 A_c f_{ck}$$

Also,

$$P_e = \frac{\pi^2 (EI_{eff})}{KL^2}$$

$$EI_{eff} = E_s I_s + C_3 E_c I_c$$

Where $C_3 = 0.6 + 2\left(\frac{A_s}{A_c + A_s}\right) \geq 0.9$

$$\lambda = \left(\frac{KL}{\pi}\right)^2 \text{X} \frac{N_c}{EI_{eff}}$$

$$F_{cr} = (0.658^{\lambda}) N_c$$

Where F_{cr} is the Flexural buckling stress

$$P_n = A_s F_{cr}$$

This observation was also made by Giakoumelis & Lam (2004), hence they proposed a modified equation to calculate failure load as

$$N_c = A_s f_y + 1.3 A_c f_{ck}$$

3.4 Chinese code (CECS 28:90)

The Chinese code (CECS 28:90) depends on unified theory that considers the concrete filled steel tube column as a composite member instead of separate components. The properties of CFST column depends upon the properties of the steel and concrete, and their dimensions. The Chinese code contrasts with both the codes that are Eurocode 4 and ACI 318. The code likewise combines shear and torsion, in addition to bending and axial load. The Chinese code CECS (28:90) proposes some necessary conditions for concrete filled steel tube members as

a) $D \geq 100$ mm
b) $t \geq 4$ mm
c) $\xi = \frac{f_y / A_s}{f_{ck} / A_c}$
d) $0.3 \geq \xi < 3$
e) D/t should be in the range of $(15 \sim 85)\sqrt{\frac{235}{f_y}}$
f) L/D should not exceed permissible limit (20 for CFST columns)

The axial load carrying capacity of concrete filled steel tube column is calculated by

$$N_u = \phi_1 \phi_2 N_o$$

ϕ_1 and ϕ_2 are the reduction factors incorporating the eccentric loading effect and slenderness influence respectively.

For concentric loading $\phi_2 = 1$ and $\phi_1 = 1 - 0.115\sqrt{\frac{l_e}{D} - 4}$ for $\left(\frac{l_e}{D}\right) > 4$

Or $\phi_1 = 1$ for $\left(\frac{l_e}{D}\right) \leq 4$

N_o is ultimate axial load carrying capacity of the short CFST columns given by

$$N_o = f_{ck} A_c \left(1 + \sqrt{\xi} + \xi\right)$$

Where ξ is the confinement factor explained by Han and Yang, mathematically given by

$$\xi = \frac{A_s f_y}{A_c f_{ck}}$$

Therefore

$$N_o = f_{ck} A_c + f_y A_s + \sqrt{f_{ck} A_c / f_y A_s}$$

ξ is an important factor which evaluates the effect of confinement on the axial strength of the concrete filled steel tube columns. The value of confinement factor depends on the area of steel by keeping the diameter of the steel tube constant and thickness is varied. The greater the thickness, greater will be the confinement factor. The values of the confinement effect may be higher for the columns of different geometric properties, but neither the corresponding strength nor the axial load capacity will be higher. It is also noted that confinement factor does not imply to the compressive strength of the concrete and the ductility of the columns.

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4. Comparison of test Results with Design Codes

4.1 Eurocode 4

The comparisons of axial load capacity of concrete filled steel tube columns with Eurocode 4 for greased and non-greased columns are listed in Table 3 and Table 4 respectively. The largest differences between experimental results and Eurocode 4 for the greased and non-greased specimens with 4 mm steel tube thickness werefound to be reduce in the range of 25.6% and 26.6% respectively for C1T4 specimen. The average N_e/N_c for the greased columns was 1.2 and for non-greased columns, it was 1.3. The least difference between experimental resultsand Eurocode 4 for the greased and non-greased specimens with 5 mm steel tube thickness was found to reduce in the range of6.6% and 9.1% individually for C3T5 specimen. It was additionally seen that with the expansion of external steel tube thickness from 4 mm to 5 mm, the load carrying capacity of CFST columns was also increased and percentage error was decreased.

Table 3: Comparisons of experimental result of greased columns and Eurocodes-4

Specimens	Experimental load capacity, N_e (kN)	Eurocode-4, N_c (kN)	N_e/N_c	% error
C1T4	823	612.1	1.3	25.6
C1T5	827	688.8	1.2	16.7
C2T4	1240	999.6	1.2	19.4
C2T5	1248	1131.2	1.1	9.4
C3T4	1714	1421.4	1.2	17.1
C3T5	1721	1607.9	1.1	6.6

Table 4: Comparisons of experimental result of non-greased columns and Eurocodes-4

Specimens	Experimental load capacity, N_e (kN)	Eurocode-4, N_c (kN)	N_e/N_c	% error
C1T4	834	612.1	1.3	26.6
C1T5	836	688.8	1.2	17.6
C2T4	1252	999.6	1.2	20.2
C2T5	1263	1131.2	1.1	10.5
C3T4	1749	1421.4	1.2	18.7
C3T5	1768	1607.9	1.1	9.1

4.2. AISC– LRFD

The comparisons of axial load capacity of concrete filled steel tube columns with AISC– LRFD for greased and non-greased specimens are listed in Table 5 and Table 6 respectively. The largest difference between experimental results and AISC– LRDF for the greased and the non-greased specimens with 4 mm steel tube thickness was found to 30.4% and 31.3% respectively for C1T4 specimen. The average N_e/P_n for the greased columns was 1.3 and for non-greased columns, it was 1.4. The least difference between experimental results and AISC– LRDF for the greased and non-greased specimens with 5 mm steel tube thickness was found to 11.8% and 14.2% respectively for C3T5 specimen. It was also observed that with the increase in outer steel tube thickness from 4 mm to 5 mm, the load carrying capacity of CFST columns was also increased and percentage error was decreased.

Table 5: Comparisons of experimental result of greased columns and AISC– LRDF

Specimens	Experimental load capacity, N_e (kN)	AISC– LRDF, P_n	N_e/P_n	% error

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		(kN)		
C1T4	823	573.0	1.4	30.4
C1T5	827	650.7	1.3	21.3
C2T4	1240	936.5	1.3	24.4
C2T5	1248	1068.9	1.2	14.4
C3T4	1714	1329.4	1.2	22.4
C3T5	1721	1517.2	1.2	11.8

Table 6: Comparisons of experimental result of non-greased columns and AISC– LRDF

Specimens	Experimental load capacity, N_e (kN)	AISC–LRDF, P_n (kN)	N_e/ P_n	% error
C1T4	834	573.0	1.5	31.3
C1T5	836	650.7	1.3	22.2
C2T4	1252	936.5	1.3	25.2
C2T5	1263	1068.9	1.2	15.4
C3T4	1749	1329.4	1.3	23.9
C3T5	1768	1517.2	1.2	14.2

4.3 ACI and AS

The American Concrete Institute (ACI) and Australian Standards (AS) provide a good prediction of the specimens with thicker (smaller D/t ratio) steel tube wall. The comparison of experimental results with ACI and AS for greased and non-greased columns is listed in Table 7 and Table 8 respectively. The largest difference in the axial capacity of concrete filled steel tube columns (C1T4) for greased and non-greased specimenswas found to 15.9% and 16.9% with 4 mm steel tube thickness between experimental results and ACI and AS. The average N_e/N_c for the greased and non-greased columns was 1.1. The least difference between experimental results and ACI and AS for the greased and non-greased specimens with 5 mm steel tube thickness was found to 1.8% and 4.4% respectively for C3T5 specimens. It was also observed that with the increase of outer steel tube thickness from 4 mm to 5 mm, the axial load carrying capacity of CFST columns was also increased and the percentage error was decreased.

Table 7: Comparisons of experimental result of greased columns and ACI, AS

Specimens	Experimental load capacity, N_e (kN)	ACI and AS, $N_{c,\ ACI,\ AS}$ (kN)	N_e/ $N_{c,\ ACI,\ AS}$	% error
C1T4	823	692.5	1.2	15.9
C1T5	827	767.7	1.1	7.2
C2T4	1240	1126.3	1.1	9.2
C2T5	1248	1155.6	1.1	7.4
C3T4	1714	1605.7	1.1	6.3
C3T5	1721	1689.7	1.0	1.8

Table 8: Comparisons of experimental result of non-greased columns and ACI, AS

Specimens	Experimental load capacity, N_e (kN)	ACI and AS, $N_{c,\ ACI,\ AS}$ (kN)	N_e/ $N_{c,\ ACI,\ AS}$	% error

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C1T4	834	692.5	1.2	16.9
C1T5	836	767.7	1.1	8.2
C2T4	1252	1126.3	1.1	10.0
C2T5	1263	1155.6	1.1	8.5
C3T4	1749	1605.7	1.1	8.2
C3T5	1768	1689.7	1.0	4.4

4.4 Chinese code (CECS 28:90)

The comparison of experimentally obtained axial load capacity of CFST column with Chinese code (CECS 28:90)for greased and non-greased columns is listed in Table 9 and Table 10 respectively. The largest difference between experimental results and Chinese code (CECS 28:90)for the greased and the non-greased specimens with 4 mm steel tube thicknesswas found to 25.5% and 26.5% respectively for C1T4 specimen. The average N_e/N_o for the greased and non-greasedcolumns was 1.2. The least difference between experimental results and Chinese code (CECS 28:90)for the greased and non-greased specimens with 5 mm steel tube thickness was found 6.6% and 9.1% respectively for C3T5 specimens. It was observed that with the increase of outer steel tube thickness from 4 mm to 5 mm, the load carrying capacity of CFST columns was also increased and percentage error was decreased.It was also observed that the comparison of results by using Chinese code (CECS 28:90) was similar to the Eurocode 4.

Table 9: Comparisons of experimental result of greased columns and Chinese code (CECS 28:90)

Specimens	Experimental load capacity, N_e (kN)	CECS 28:90, N_o (kN)	N_e/ N_o	% error
C1T4	823	612.9	1.3	25.5
C1T5	827	689.7	1.2	16.6
C2T4	1240	999.7	1.2	19.4
C2T5	1248	1131.2	1.1	9.4
C3T4	1714	1421.5	1.2	17.1
C3T5	1721	1608.0	1.1	6.6

Table 10: Comparisons of experimental result of non-greased columns and Chinese code (CECS 28:90)

Specimens	Experimental load capacity, N_e (kN)	CECS 28:90, N_o (kN)	N_e/ N_o	% error
C1T4	834	612.9	1.3	26.5
C1T5	836	689.7	1.2	17.5
C2T4	1252	999.7	1.2	20.2
C2T5	1263	1131.2	1.1	10.4
C3T4	1749	1421.5	1.2	18.7
C3T5	1768	1608.0	1.1	9.1

5. Conclusions

The accompanying ends are drawn from this examination:

1. There is negligible huge increment in the pivotal burden limit of cement filled steel tube segment for non-lubed examples contrasted with the lubed specimensdue with nearby clasping of steel tube. The expansion in the pivotal burden limit with respect to the examples with thinnersteel tube thickness is significantly less than the thicker ones.

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2. The Eurocode-4 plan technique considers the impact of burden capriciousness and thinness proportion on the imprisonment impact in the solid filled steel tube sections.

3. The burden conveying limit of cement filled steel tube segments increments with decline in the proportion of width of steel cylinder to the thickness of steel tube (D/t).

4. The correlation among Eurocode-4, AISC-LRFD, ACI, AS and CECS 28:90 showedthat AISC-LRFD gives traditionalist outcomes for both lubed and non-lubed examples.

5. The Chinese code (CECS 28:90) is just material for assessing the hub quality of cement filled steel tube sections having steel tube thickness 4mm and the sky is the limit from there.

6. The Chinese code (CECS 28:90) and Eurocode 4 gives the comparative aftereffects of hub load capacityfor both lubed and non-lubed concrete filled steel tube segments.

6. Slenderness proportion assumes an indispensable job in the quality count of segment and its conduct. As the thinness proportion expands, a definitive quality abatements.

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