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Comparative Study of Concrete Filled Steel Tube Columns under Axial Compression

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Abstract: *In recent days, due to the expansion of cities it is required to construct the high storey buildings. Composite buildings prove to be promising for multi storey building. As a result, composite columns have recently undergone increased usage throughout the world, which has been influenced by the improvement of high strength concrete enabling these columns to be considerably economized. Columns are designed to resist the majority of axial force by concrete alone can be further economized by the use of thin walled steel tube. The paper discusses about the behavior of the composite column and various codal provisions. Experimental research carried out by comparative study between experimental results and analytical results for hollow steel tube (HST) and concrete filled steel tubes (CFST) under axial compression. To compare the experimental results of CFST with AISC-LRFD 2005 and Eurocode-4. The investigation is carried out on HST & CFST specimens of Rectangular cross section with three different sizes. The grade of concrete used for infill concrete is M20 and M40. The tests on said CFST specimens are carried out with the help of compression testing machine. The axial load is applied gradually on specimens. This paper presents the details of study carried out and the conclusions arrived.*

Keywords: *HST, CFST, AISC-LRFD, in filled concrete, buckling etc.,*

1. INTRODUCTION

Concrete filled steel tubular (CFST) members utilize the advantages of both steel and concrete. They comprise of a steel hollow section of circular or rectangular shape filled with plain or reinforced concrete. They are widely used in high-rise and multistory buildings as columns and beam-columns, and as beams in low-rise industrial buildings where a robust and efficient structural system is required.

There are a number of distinct advantages related to such structural systems in both terms of structural performance and construction sequence. The inherent buckling problem related to thin-walled steel tubes is either prevented or delayed due to the presence of the concrete core. Furthermore, the performance of the concrete in-fill is improved due to confinement effect exerted by the steel shell. The distribution of materials in the cross section also makes the system very efficient in term of its structural performance. The steel lies at the outer perimeter where it performs most effectively in tension and bending. It also provides the greatest stiffness as the material lies furthest from the centroid. This, combined with the steel's much greater modulus of elasticity, provides the greatest contribution to the moment of inertia. The concrete core gives the greater contribution to resisting axial compression.

The hollow tubes alone were designed in such a way that they are capable of supporting the floor load up to three or four storey height. Once the upper floors were completed, the concrete was pumped into the tubes from the bottom. To facilitate easy pumping the tubes were continuous at the floor level. Modern pumping facility and high performance concrete make pumping three or four storey readily achievable. Due to the simplicity of the construction sequence, the project can be completed in great pace.

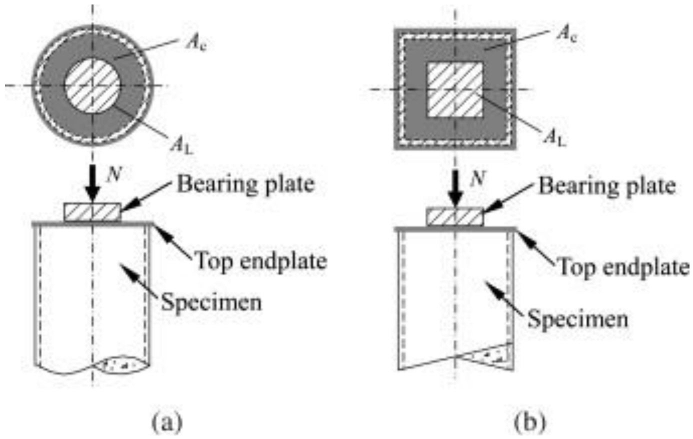

Fig. *Shows plan and section of CFST columns*

2. EXPERIMENTAL WORK

For experimental investigation axial load is applied on HST & CFST specimen. While testing care taken that the end surfaces on which concrete filled steel tubes keeping for testing should be the plane. All specimens were tested in Compression Testing Machine and are simply supported at both ends.

Details of column specimens:

- All the steel tubes have same c/s as **145mm X 82mm X 4.8mm**.
- A total of **18 columns** were tested (6 HST and 12 CFST).
- **2 HST** and **2 CFST** columns of height **0.5m** were tested for axial compression loading.
- **2 HST** and **2 CFST** columns of height **1m** were tested for axial compression loading.
- **2 HST** and **2 CFST** columns of height **1.5m** were tested for axial compression loading.

Materials used are:

1. Hollow steel tubular section
2. Nitowrap 410 (epoxy)
3. Cement
4. Fine aggregate
5. Coarse aggregate
6. Steel bars
7. Water
8. Curing compound

Table1. *Details of column specimens*

Sl. No.	Specimen designation	Dimensions (mm)			Length (mm)	L/D	Concrete Grade
		(B)	(D)	(t)			
1	HSTC-01	82	145	4.8	500	3.45	…..
2	HSTC-02	82	145	4.8	500	3.45	…..
3	HSTC-03	82	145	4.8	1000	6.90	…..
4	HSTC-04	82	145	4.8	1000	6.90	…..
5	HSTC-05	82	145	4.8	1500	10.34	…..
6	HSTC-06	82	145	4.8	1500	10.34	…..
7	CFSTC-01	82	145	4.8	500	3.45	M20
8	CFSTC-02	82	145	4.8	500	3.45	M20
9	CFSTC-03	82	145	4.8	500	3.45	M40
10	CFSTC-04	82	145	4.8	500	3.45	M40
11	CFSTC-05	82	145	4.8	1000	6.90	M20
12	CFSTC-06	82	145	4.8	1000	6.90	M20
13	CFSTC-07	82	145	4.8	1000	6.90	M40
14	CFSTC-08	82	145	4.8	1000	6.90	M40
15	CFSTC-09	82	145	4.8	1500	10.34	M20
16	CFSTC-10	82	145	4.8	1500	10.34	M20
17	CFSTC-11	82	145	4.8	1500	10.34	M40
18	CFSTC-12	82	145	4.8	1500	10.34	M40

Properties of the basic materials:

1. **Hollow steel tubes:** It confirms to IS-4923:1997

Table2. *Dimensions and geometrical properties of RHS*

Grade of Steel	Minimum Yield Stress (MPa)	Minimum Tensile Stress (MPa)	Percentage Elongation, Min for sizes (%)	
			Less than or equal to 25.4mm	Greater than 25.4mm
Yst 310	310	450	8	10

Table3. *Mechanical Properties of Cold Formed Steel Section*

RHS	Thickness	Sectional Area	Weight	Moment of Inertia		Radius of Gyration		Elastic Modulus	
(D x B)	(t)	(A)	(W)	(I_{xx})	(I_{yy})	(r_{xx})	(r_{yy})	(Z_{xx})	(Z_{yy})
mm	mm	cm^2	kg/m	cm^4	cm^4	cm	cm	cm^3	cm^3
145 X 82	4.8	20.28	15.92	555.16	228.5	5.23	3.36	55.73	94.93

2. **Cement:** OPC 53 grade cement confirming to IS 12269:1987 is used in the current investigation.

Table4. *Properties of Cement*

Serial No	Characteristics		Results	Requirements as per IS 12269 -1987
1	Fineness		340 m^2/kg	Should be more than 225m^2/kg
2	Soundness		4mm	Should be less than or equal to 10mm
3	Setting Time	Initial	125 minutes	Should be more than 30 minutes
		Final	220 minutes	Should be less than or equal to 600minutes
4	Specific Gravity		3.13	....
5	Standard Consistency		32.40%	....

3. **Fine aggregate:** Manufactured sand confirming to IS-383:1970 belonging to zone II is used in the current investigation.

Table5. *Properties of Manufactured sand*

1	Bulk Density (kg/ m^3)	1540
2	Specific Gravity	2.59
3	Fineness Modulus	2.97
4	Water Absorption	4.5%

4. **Coarse aggregate:** Crushed stone aggregates confirming to IS 383:1970 were used as coarse aggregates. The maximum size of crushed stone dust was 12.5mm. The specific gravity of crushed stone aggregate used was found to be 2.63 and the water absorption was found to be 0.72%.

5. **Chemical admixture:** The chemical admixture basically used in the concrete for current experimental investigation is a high performance super plasticizer which is derived from carboxylic ether.

Table6. *Characteristics of Master Glenium Sky 8630*

SI.No.	Properties	Values
1	Specific Gravity	1.08
2	Chloride ion content	0.0075
3	Relative Density	1.075 at 25^0 C
4	p^H	6.77

Concrete: The concrete used in the current experimental investigation was produced in the Ready Mix Concrete (RMC) plant. Two grades of concrete M_{20} and M_{40} were used. Both the concrete had collapsible slump so that concrete can easily flow into the steel tube by its own.

6. **Curing compound:** The curing compound used in the current experimental investigation was basically based the membrane curing theory. The curing compound used is Master Kure 181 which is a non degrading, membrane forming liquid basically derived from the acrylic resin.

Table7. *Characteristics of Master Kure 181*

SI.No.	Properties	Values
1	Specific Gravity	0.82 at 25^0 C
2	Flash Point	30^0 C
3	Drying Time	45 minutes at 25^0 C

Fig. *CFST columns before and after application of curing compound*

Experimental Test Setup:

The concrete filled steel tube specimens of different cross sections are tested for their load carrying capacity under axial compression on the compression testing machine. The actual test setup is as shown in following figure. The specimen of CFST is placed centrally on plates of compression testing machine and load is applied gradually. The capacity of compression testing machine in our college is 200 tonne. The readings werw taken on dial guage and tabulated.

Fig. *Test set up of CFST Column for axial loading*

Table8. *Test results of HSTC-03 to HSTC-06*

Sl. No	Specimen Designation	Height of Column (m)	Ultimate Axial Compressive Load (kN)
1	HSTC-03	1.0	688.66
2	HSTC-04	1.0	680.81
3	HSTC-05	1.5	608.22
4	HSTC-06	1.5	622.94

Hollow Steel Tubular Column (HSTC-05 to HSTC-12)

Table9. *Test results of HSTC-05 to HSTC-12*

Sl. No	Specimen Designation	Height of Column (m)	Grade of concrete infilled	Ultimate Axial Compressive Load (kN)
1	HSTC-05	1.0	M_{20}	797.55
2	HSTC-06	1.0	M_{20}	808.34
3	HSTC-07	1.0	M_{20}	819.14
4	HSTC-08	1.0	M_{20}	830.91
5	HSTC-09	1.5	M_{40}	725.94
6	HSTC-10	1.5	M_{40}	741.64
7	HSTC-11	1.5	M_{40}	755.37
8	HSTC-12	1.5	M_{40}	769.10

3. COMPARISON OF TEST RESULTS WITH CODES

EUROCODE 4:

In this research, similar to for end –loaded braced members, the axial force Nsd and the maximum end moment Msd are determined from a first order structural analysis. For each of the bending axis of the column it has to be verified that

$$N_{Sd} \leq \chi_k N_0$$

Where χ_k is a reduction factor due to buckling. The buckling curves can also be described in the form of an equation:

$$\chi_k = \frac{1}{\phi + \sqrt{\phi^2 - \overline{\lambda}^2}}$$

Where,

$$\phi = 0.5[1 + \alpha(\overline{\lambda} - 0.2) + \overline{\lambda}^2]$$

Where α depends on the buckling effects, a value of 0.21 was adopted for CFST column. The relative slenderness of λ is given by:

$$\overline{\lambda} = \sqrt{\frac{N_0}{N_{cr}}}$$

In which N_{cr} is the critical buckling stress resultant given by:

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

Where Le is the effective length and $(EI)_e$ is the actual elastic stiffness.

$$(EI)_e = E_s I_s + 0.8 \frac{E_c}{1.35} I_c$$

In this research it is proposed:

$$(EI)_e = E_s I_s + 0.8\beta_c E_c I_c$$

Where β_c is the load effect;

I_c, I_s are the concrete , steel moments of inertia;

E_s is the Young's modulus of steel;

E_c is the secant modulus for the concrete determined for the appropriate concrete grades, equal to $9500(f_c'+8)^{1/3}$ In MPa:

F_c' is the characteristic compressive cylinder strength of concrete at 28 days.

AISC-LFRD 2005:

$\mathbf{P_n}=A_sF_{cr}$

$(0.658^{\lambda_c^2})F_{my}$ $(\lambda_c\leq1.5)$

$F_{cr}=\{$

$(0.877/\lambda_c^2)F_{my}$ $(\lambda_c>1.5)$ r_m

A_c A_z

$\lambda_c=\frac{KL}{rm\pi}\sqrt{\frac{Fmy}{Em}}$

$F_{my}=f_y+0.85f_c^1(\frac{Ac}{Az})$

$E_m=E_z+0.4(\frac{Ac}{Az})E_c$

$E_c=W^{1.5\sqrt{f}_c^{\,1}}$

Table10. *Comparison of experimental ultimate loads and design ultimate loads*

Serial No	Specimen Designation	Experimental Ultimate Load(P_{EXP}) (kN)	Predicted Design Load by AISC-LRFD-2005		Predicted Design Load by Eurocode-4	
			P_{LRFD} (kN)	P_{EXP}/P_{LRFD}	P_{EC4} (kN)	P_{EXP}/P_{EC4}
1	CFSTC-1	884.86	752.08	1.18	787.03	1.12
2	CFSTC-2	912.33	752.08	1.21	787.30	1.16
3	CFSTC-3	1020.24	883.33	1.15	943.21	1.08
4	CFSTC-4	1059.48	883.33	1.20	943.21	1.12
5	CFSTC-5	797.55	719.22	1.11	752.40	1.06
6	CFSTC-6	808.33	719.22	1.12	752.40	1.07
7	CFSTC-7	819.14	840.81	0.97	895.41	0.91
8	CFSTC-8	830.91	840.81	0.99	895.41	0.93
9	CFSTC-9	725.94	667.62	1.09	705.26	1.03
10	CFSTC-10	741.64	667.62	1.11	705.26	1.05
11	CFSTC-11	755.64	774.45	0.98	826.65	0.91
12	CFSTC-12	769.10	774.45	0.99	826.65	0.93

4. CONCLUSIONS

- The axial load carrying capacity of CFST columns was increased by

  19.3% and 38% for M_{20} and M_{40}.

  17.3% and 22.2% for M_{20} and M_{40}.

  19.7% and 24.3% for M_{20} and M_{40}.

- The average ultimate load carrying capacity of Concrete Filled Steel Tubular frames was increased by

  22.5% and 48.9% for M_{20} and M_{40}.

- The theoretical axial load carrying capacity of Concrete Filled Steel Tubular columns evaluated in accordance with AISC-LRFD 2005 and Eurocode 4 were found to be in best agreement.
- The maximum percentage variation for experimental results and theoretical results of axial load carrying capacity of CFST columns evaluated in accordance with

  AISC-LRFD 2005 was around 21%.

  Eurocode 4 was around 16%.
- Although there was some variation in the results between the experimental and theoretical results, but the experimental results were on the conservative side.
- The failure of the CFST columns of height 0.5m was basically due to the local buckling near the mid height compare to the failure of Hollow Steel Tubular columns which failed due to inward local buckling near the ends.
- The failures of the CFST columns of height 1.0m and 1.5m were basically due to the overall buckling which was very much similar in case of Hollow Steel Tubular columns.

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