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An Experimental and Analytical Investigation on the Behaviour of Concrete Filled Steel Tubular Columns and Frames

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Abstract:— **In this paper an attempt has been made to investigate the axial load carrying capacity of Concrete Filled Steel Tubular (CFST) columns. The grade of concrete is also one parameter which is studied in the present work. A total of 18 specimens were tested for axial compression. The height of compression members (columns) being 0.5m, 1.0m and 1.5m. Two empty hollow steel tubular columns for height 0.5m, 1m and 1.5m and two each for Concrete filled Steel Tube (CFST) columns for height 0.5m, 1.0m and 1.5m for M20 and M40 grade of concrete were tested. Finally Eurocode 4 and AISC-LRFD 2005 codes were used to compare the experimental results of Concrete Filled Steel Tubular (CFST) columns. The experimental results indicated that there was increase in the axial load carrying capacity of CFST columns from 17.3% to 19.7% and 22.2% to 38% for CFST columns filled with M20 and M40 grade of concrete respectively. 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%. The maximum percentage variation for experimental results and theoretical results of axial load carrying capacity of CFST columns evaluated in accordance with 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.**

Key word:-- **CFST, Concrete, columns, frames, epoxy, curing compound.**

I. INTRODUCTION

The Concrete Filled Steel Tube (CFST) structural system is one kind of composite structural system in which hollow structural steel tube (such as circular, square, rectangular, pentagonal, hexagonal, etc) is filled with concrete. CFST is one of the modern composite concrete steel structure currently gaining momentum in construction field. Since hollow structural steel tube is filled with concrete, the interior concrete core is confined by the steel tube from the outer periphery which increases the compressive strength of concrete core. Moreover the interior concrete core prevents or delays the local buckling of the hollow structural steel tube from the inner periphery of the steel tube. Since steel tube is part of composite member, there is no necessity of formwork. The cost of formwork will get reduced since steel tube itself acts like permanent formwork. The steel tube works like both the transverse and longitudinal reinforcement. Hence the reinforcement is in the form of steel tube which is continuous throughout the section. Combining the advantages of together the concrete and hollow structural steel tube, Concrete Filled Steel Tubes (CFSTs) especially the Rectangular Concrete Filled Steel Tubes (RCFSTs) are predominantly used in modern construction projects due to their outstanding static and dynamic (such as earthquake forces, wind forces.., etc) resistance characteristics, such as good strength, superior ductility and high energy absorption capacity.

A couple of decades ago, the behaviour of Concrete Filled Steel Tubular (CFST) columns in axial compression and beams for flexure have been studied but yet the complete knowledge of CFST is not attained. It is important to note that the economical and mechanical benefits could be achieved if CFST columns are constructed considering the advantages of materials which have high strength. Let us take the example of CFST columns wherein the infill concrete has good compressive strength which contributes towards the damping and stiffness of CFST columns compare to normal RCC columns. Furthermore, CFST column needs considerably slender cross section to resist the loads, this makes the extra space for the carpet area which is appreciated by builders and architects. One of the most important advantage of CFST is the interaction between the steel tube and concrete wherein the local buckling of steel tube is either prevented or delayed by interior concrete core and steel tube provides sufficient confinement to the interior concrete core thereby increasing the strength of concrete core. Concrete Filled Steel Tubes (CFSTs) are used mainly in many structural applications such as bridge piers, roofs of the storage tanks, cable stayed bridges, suspension bridges, arch bridges, offshore platforms and columns in seismic locations.[1]

In 2004, a truss pedestrian bridge of span 60m was constructed in Quebec, Canada utilising the high reactive powder concrete, which has been confined as well as pressed in to the hollow steel tubes which in the truss bridge acts like diagonal members.[2]

Application of the CFST structural system might lead to 60% total saving of steel when compare to conventional structural steel system. Since steel tube acts as well distributed reinforcement, concrete core prevents or delays the local buckling and hence makes the steel tube to buckle outwards instead of inwards which increases the flexural strength of the CFST members. However confinement effectiveness may get reduced a little bit if sections other than circular and elliptical are used but it will provide the resistance against the flexure.[3]

II. EXPERIMENTAL PROGRAMME

2.1 Materials

2.1.1 Cement: Ordinary Portland Cement (OPC) confirming to IS 12269:1987 is used which has specific gravity of 3.13. Table 1 gives the properties of cement.

Table 1: Properties of Cement

Particulars	Test Results
Fineness (m^2/kg)	340
Normal Consistency (%)	32.4
Initial Setting Time	125
Final Setting Time	220
Specific Gravity	3.13

2.1.2 Fine Aggregate: The fine aggregate which is used in current investigation was Manufactured Sand (M sand). The grading of sand was done as per IS 383:1970. It belongs to zone II and has specific gravity of 2.59.

2.1.3 Coarse Aggregate: Crushed stone aggregates confirming to IS 393:1970 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%.

2.1.4 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.

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

2.1.6 Epoxy: The epoxy which is used in the current experimental investigation is Nitobond EP. This is basically used for bonding the two adjoining surfaces. This epoxy used acts as bonding agent between the concrete which is inside the tube and internal surface of hollow steel tube.

2.1.7 Hollow Steel Tube: Tata Structura Rectangular Hollow Sections (RHS) having a yield stress of 310MPa are used, which confirms to IS-4923:1997. Figure 1 shows the cross section of hollow steel tube.

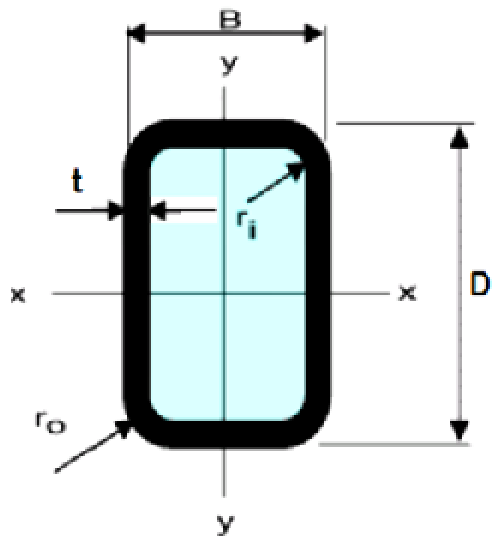

Fig 1: Cross section of Hollow Steel Tube

2.2 Details of specimens: All the specimens consist of Rectangular Hollow Steel tube of dimensions 145mm x 82mm and having a thickness of 4.8mm. It is filled with two grades of concrete M20 and M40. Table 2 gives details of column specimens as shown below.

Table 2: Details of column specimens

Sl. No.	Specimen designation	Length (mm)	Concrete Grade
1	HSTC-01	500	....

2	HSTC-02	500	....
3	HSTC-03	1000	....
4	HSTC-04	1000	....
5	HSTC-05	1500	....
6	HSTC-06	1500	....
7	CFSTC-01	500	M_{20}
8	CFSTC-02	500	M_{20}
9	CFSTC-03	500	M_{40}
10	CFSTC-04	500	M_{40}
11	CFSTC-05	1000	M_{20}
12	CFSTC-06	1000	M_{20}
13	CFSTC-07	1000	M_{40}
14	CFSTC-08	1000	M_{40}
15	CFSTC-09	1500	M_{20}
16	CFSTC-10	1500	M_{20}
17	CFSTC-11	1500	M_{40}
18	CFSTC-12	1500	M_{40}

A total of 18 column specimens were tested for axial compression, 6 each for 0.5m, 1.0m and 1.5m. Out of these, two were hollow, two were filled with M20 and two were filled with M40 grade of concrete.

In addition to the above, a total of 9 frames were tested, out of which, three frames were hollow, three frames were filled with M20 grade of concrete and three frames were filled with M40 grade of concrete. Each frame consists of a beam of span 1m and a column of height 1m. The connections between beam and column are designed as simple frame connections having a seat angle of ISA 100 X 100 X 8mm using filled welding having throat thickness of 6mm.

Fig 2: Finishing to the concrete exposed surfaces of frames and column.

Fig 3: CFST columns before and after application of curing compound.

2.3 Experimental Set up: All the CFST column specimens were tested for axial compression whereas all the CFST frames were tested for two point loading at one third of effective span.

Figure 4 shows the Universal Testing Machine (UTM) of 1000kN capacity where in the testing of hollow steel tubular columns of height 0.5m was carried out. The demec strain gauge was installed at mid height to measure the axial compressive strain and dial gauge was installed in order to measure the mid height deflection. The load was applied till the failure of the specimen and ultimate load was noted down.

Fig 4: Test setup for testing of Hollow Steel Tubular Columns in UTM.

Figure 5 shows the Compression Testing Machine of 2000kN capacity where in the testing of Concrete Filled Steel Tubular columns were carried out. Digital Demec strain gauge was installed at the mid height in order to measure the axial compressive strain and dial gauge having magnetic base was installed at mid height so as to measure the mid height deflection. The CFST columns were loaded up to failure load. The failure load of axial compression was noted down. The axial compressive strains and mid height deflections were measured at a regular interval of 25kN.

Fig 5: Test setup for testing of CFST columns of 0.5m height in CTM.

Figure 6 shows the experimental set up for testing of CFST columns of 1m and 1.5m height. The CFST columns were tested in a 1000kN capacity loading frame. The monotonic load was applied through the 1000kN capacity hydraulic jack. The load cell was attached to the hydraulic jack to note down the axial load in tonnes. The axial load was increased uniformly up to the failure of the specimen. Only ultimate axial load was noted down.

Figure 7 shows the experimental set up for the testing of CFST frames having span of beam as 1m and height of column as 1m. The CFST frames were tested in a 2000kN capacity frame. The monotonic load was applied through the 1000kN capacity hydraulic jack and load was measured with a proving ring of 1000kN capacity. Two rollers were placed normal to the plane of CFST frame in order to prevent the lateral movement of the frame and also to make sure that the load is applied in plane of the frame.

Fig 6: Test setup for testing of CFST columns of 1m and 1.5m.

***Fig 7: Test set up for the testing of CFST frames*.**

III. EXPERIMENTAL RESULTS

The results of experiments conducted on CFST columns and frames are presented in detail here. For the CFST columns of height 0.5m, axial compressive loads, axial compressive strains and mid height deflections have been recorded where as for CFST columns of height 1.0m and 1.5m, only ultimate compressive loads have been recorded. For the CFST frames, ultimate loads and deflections at mid span and deflections at quarter span on either side of mid span have been recorded. The graphs of axial compressive load verses axial compressive strain and axial compressive load verses mid height deflection have been plotted for CFST columns of 0.5m height. For the case of CFST frames, the graphs of load verses mid span deflection have been plotted. Table 3 shows the test results of all hollow and Concrete Filled Steel Tubular Columns.

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Table3: Test results of columns

Sl. No	Axial Load in kN	Axial Strain	Mid height deflection in mm
1	749.5	0.00042	1.885
2	757.3	0.000415	1.897
3	688.7	----------	--------
4	680.8	----------	--------
5	608.2	----------	--------
6	622.9	----------	--------
7	912.3	0.002075	10.756
8	884.9	0.001990	10.495
9	1020.2	0.001490	7.956
10	1059.5	0.001395	7.621
11	797.6	----------	--------
12	808.3	----------	--------
13	819.1	----------	--------
14	830.9	----------	--------
15	725.9	----------	--------
16	741.6	----------	--------
17	755.4	----------	--------
18	769.1	----------	--------

Table 4 shows the experimental results of CFST and HST frames. The ultimate loads and mid span deflections were recorded. The two point loading was applied as subjected to pure bending.

Table 4: Test results of frames

Sl. No	Specimen Details	Ultimate load in kN	Ultimate mid span deflection
1	HSTF-1	225	7.359
2	HSTF-2	230	7.779
3	HSTF-3	220	5.945
4	CFSTF-1	270	7.191
5	CFSTF-2	280	6.791
6	CFSTF-3	275	7.155
7	CFSTF-4	325	6.821
8	CFSTF-5	330	6.641
9	CFSTF-6	350	6.582

Following figures shows the failure of the column and frame specimens which are hollow and filled with concrete.

Fig 8: Failure of HSTC-01.

Fig 9: Failure of CFSTC-03 due to local buckling near mid height.

Fig 10: Connection failure of the specimen HSTF-01

Fig 11: Concrete crushing in the beam portion of CFST frame

IV. CONCLUSIONS

1. The average axial load carrying capacity of Concrete Filled Steel Tubular columns of height 0.5m was increased by 19.3% and 38% for M20 and M40 grade of concrete respectively.
2. The average axial load carrying capacity of Concrete Filled Steel Tubular columns of height 1.0m was increased by 17.3% and 22.2% for M20 and M40 grade of concrete respectively.
3. The average axial load carrying capacity of Concrete Filled Steel Tubular columns of height 1.5m was increased by 19.7% and 24.3% for M20 and M40 grade of concrete respectively.
4. The average ultimate load carrying capacity of Concrete Filled Steel Tubular frames was increased by 22.5% and 48.9% for M20 and M40 grade of concrete respectively.
5. 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.
6. 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.
7. The failure of Hollow Steel Tubular frames was mainly due to the failure of the connection between the column and beam of the frames.
8. The failure of CFST frames was due to the combined failure of the connection between the beam and column of the frame and crushing of concrete for the beam at the compression face.
9. The results of the current investigation also showed that catastrophic failure in case of CFST columns and frames was considerably very less.
10. All in all, the CFST column and frames performed better compare to the Hollow Steel Tubular columns and frames. Hence it can replace the conventional RCC composite constructions.

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