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RESEARCH ARTICLE

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COMPARATIVE STUDY OF CONCRETE FILLED STEEL TUBES UNDER AXIAL COMPRESSION

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ABSTRACT

This paper deals with comparative study between experimental results and analytical results obtained by linear finite element analysis, for concrete filled steel tubes (CFST) under axial compression. For the purpose of finite element analysis 'ABAQUS 6.13.1' software is used. The experimental investigation is carried out on CFST specimens of three different cross sections viz. Circular, Square and Rectangular with each having two different sizes. The grade of concrete used for infill concrete is M20, M30 and M40. The tests on said CFST specimens is carried out with the help of compression testing machine. The axial load is applied gradually on specimens. The finite element analysis is done with 'ABAQUS' software by creating models of same specifications used for experimental investigation. While analyzing model in 'ABAQUS' software the experimental axial displacement is used for calculating load carrying capacity. The stress distribution and displacement diagrams are also shown in this paper. Experimental and analytical results are compared. From which it is observed that analytical results are in good agreement with experimental results. This paper presents the details of study carried out and the conclusions arrived.

Keywords— CFST, Finite element analysis, ABAQUS, Axial load, axial displacement, Load carrying capacity.

INTRODUCTION

Preamable:

In the Concrete Filled Steel Tube (CFST) Structural System high-strength concrete is used for filling steel tubes. These members are ideally suited for all applications because of their effective usage of construction material. In this type of composite members, the advantages of both hollow structural steel (HSS) and concrete is utilized. CFST having excellent static and earthquake resistant properties and due to which, they are being used widely in real civil engineering projects. Concrete filled steel tubes possess properties such as high strength, high ductility and large energy absorption capacity. When these types of composite members are used as structural columns, especially in high-rise buildings, CFST may be subjected to high shearing force as well as moments due to wind or seismic actions. Therefore it is very important to study the behaviour of CFST Columns in axial compression. From many research studies it is observed that it gives mechanical and economic benefits when high strength concrete infill is used, which contributes greater damping and stiffness to CFST columns compare to normal strength concrete. Due to high strength concrete infill, CFST columns require a smaller cross section to withstand the load, which is appreciated by architects and building engineers.

Local buckling is delayed due to interaction between concrete and steel tube and this is the main advantage of CFST, along with which steel tubes provided sufficient confining effect to concrete. The enhancement of CFST column in structural system is due to composite action between steel and concrete. The steel tube itself acts as longitudinal and transverse reinforcement. The shell also provides confining pressure to the concrete, which puts concrete under tri-axial state of stress, and concrete infill increase the stiffness of column, which prevents the inward buckling of steel tube, and increases the stability and the strength of column system, resulting in higher flexural strength. Therefore tubes with thinner walls could reach the yielding strength before local buckling. Under axial compression, the steel tube confines the concrete, therefore improves both axial load resistance and ductility of CFST members. Steel tubes were also used as permanent formwork and the well distributed reinforcement located at most efficient position. Due to large shear capacity of concrete filled steel tubular members, they predominantly fail in flexure in a ductile manner. Confinement effectiveness may be reduced to bit if rectangular or square tubes are filled up with high strength concrete but it provides advantage against flexure.

Behaviour of concrete filled steel tubes:

Many studies have shown that the performance of a square concrete-filled steel tube (CFST) is not as good compare to its circular counterpart. This is due to the fact that a square steel tube could only provide less confining pressure to the concrete core, and that its local buckling is more likely to occur.

The structural behaviour of CFST elements are considerably affected by the difference between the Poisson's ratios of the steel tube and concrete core. In the initial stage of loading, the poisons ratio for the concrete is lower than that of steel. Thus, the steel tube has no confining effect on the concrete core. As longitudinal strain increases, the lateral expansion of concrete gradually becomes greater than expansion of steel tube. At this stage, the concrete core becomes tri-axially and steel tube bi-axially stressed. The steel tube under a biaxial state cannot sustain the normal yield stress, causing a transfer of load from tube to the core. The load transfer mechanism is similar for square and circular CFST elements. In the first stage of loading the steel tube sustains most of the load until it yields. At this point (a) there is a load transfer from steel tube to the concrete core. The steel tube exhibits a gradual decrease in load sharing until the concrete reaches its maximum compressive strength (a to b). After this stage of loading (point b), there is redistribution of load from concrete core to the steel tube. At this point (b) the steel exhibits a hardening behavior with almost the same slope as in uniaxial stress-strain hardening relationship.

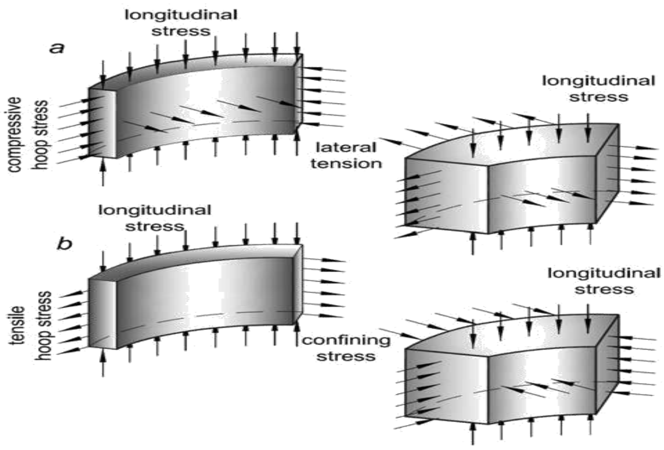

Fig 1: Stress condition in steel tube and concrete core at different stages of loading:

EXPERIMENTAL WORK

For experimental investigation axial load is applied on 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.

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 ton. The readings were taken on dial gauge and tabulated.

Fig-2: Photograph of Test setup for CFST on Compression Testing Machine.

Grade of concrete:

The concrete infill used for CFST are of M20, M30 and M40 grades. The proportions obtained by mix design of concrete by using IS 10262:1982. The concrete blocks of size 150mm x150mm x 150mm are prepared by obtained proportions. Three blocks are casted by each proportion and tests were carried out under compression testing machine.

Table 1: 28 day's strength for M20, M30 and M40 grade of concrete block

Grade of concrete	Load in kN	Avg. strength in N/mm^2
M20	627.37	27.88
M30	793.90	35.15
M40	962.83	42.75

Steel Tube Specimen details:

For experimental investigation three different cross sectional steel tubes were used viz. circular, square and rectangular section. All specimens are prepared from mild steel grade steel pipes. For each cross sections three specimens were tested and the average value of load carrying capacity is taken for further studies. The details of steel tubes are tabulated in table 2

Table 2: Steel tube Specimen details

Cross Section	Inner dimensions in mm	Length in mm	Thk. t in mm	D/t	L/t	Marked as
Circular	Dia = 55.8	300	1.3	44.92	5.14	C1
	Dia =72.1	300	2	38.05	5.14	C2
Square	48.3x 48.3	300	1.2	42.25	5.91	S1
	69 x 69	300	1.7	42.59	5.91	S2
Rectangular	38 x 77.4	300	1.3	31.23	7.39	R1
	43.3 x93.3	300	2	23.65	6.34	R2

Fig-3: Steel tubes for casting of CFST specimens

Fig-4: CFST Specimens immediate after casting.

Fig-5: CFST Specimens after 28 days curing, before testing.

Failure pattern:

The failure pattern of concrete filled steel tubes is different for different cross sections. CFST specimens with circular cross section fails in length due to distortional buckling. The experimental failure is not uniform overall. It fails at some point in upper half part of specimens. The CFST Specimens with square and rectangular cross sections are failed at both ends of tube due to local buckling. The failure pattern for CFST specimens with all grades of concrete is near about same as stated above.

Fig-6: Failure Pattern of CFST Specimens

FINITE ELEMENT ANALYSIS

Load carrying capacity and comparison with experimental results:

ABAQUS standard 6.13-1 is used for analytical study. Concrete core and steel pipe both are consider as solid homogeneous elements. No inter-particle friction is considered. Only linear analysis is done. Load is applied according to final axial deformation observed at experimental failure of specimen. The final load carrying capacity is calculated for the same final axial deformation in ABAQUS software which is shown in deflection output diagram. UDL pressure load is applied at the end. Stress distribution, deflections pattern, are studied. Steel materials employed in the specimens were modeled as isotropic. The value of modulus of elasticity is considered to be $2.1x10^5$ N/ mm^2 and the Poisson ratio was 0.3. Concrete properties in the specimens were molded as isotropic. The value of modulus of elasticity is calculated using formula $5000 \text{ x} \sqrt{f_{ck}}$ from IS 456-2000. Theoretical results obtained by ABAQUS are quite comparable with experimental results. However, non-linear analysis need to be made to predict behaviour of concrete filled steel tubes under axial compression.

Table 3: Comparison between experimental test results and analytical results from ABAQUS

Specimen marked	Concrete grade	Axial deformation at failure in mm	Expt. L.C.C. in kN (N_e)	L.C.C. by ABAQUS in kN (N_a)	Ratio Ne/Na
C1	M20	8.0 x 10^{-1}	153.69	165.54	1.08
C2	M20	9.0 x 10-1	268.14	309.13	1.15
S1	M20	8.0 x 10-1	134.07	149.46	1.11
S2	M20	8.0 x 10-1	264.87	314.50	1.19
R1	M20	7.0 x 10-1	153.69	170.11	1.11
R2	M20	8.0 x 10-1	238.71	259.03	1.08
C1	M30	8.0 x 10-1	182.12	199.81	1.10
C2	M30	9.0 x 10-1	310.65	372.78	1.20
S1	M30	8.0 x 10-1	166.77	181.31	1.09
S2	M30	8.0 x 10-1	313.52	382.65	1.22
R1	M30	7.0 x 10-1	183.12	201.04	1.09
R2	M30	8.0 x 10-1	264.87	315.15	1.19
C1	M40	8.0 x 10-1	209.28	236.45	1.13
C2	M40	9.0 x 10-1	340.08	431.88	1.26
S1	M40	8.0 x 10-1	179.85	208.27	1.16
S2	M40	8.0 x 10-1	346.62	445.55	1.28
R1	M40	7.0 x 10-1	209.28	228.88	1.09
R2	M40	8.0 x 10-1	304.11	371.27	1.22

Stress distribution and Displacement diagrams:

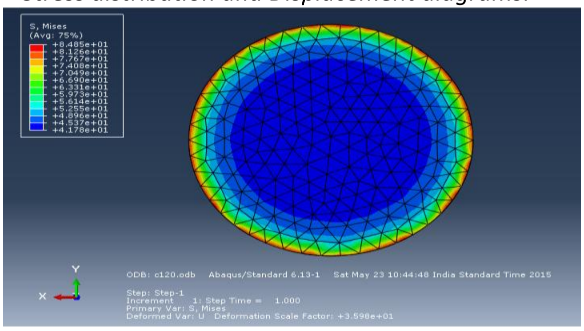

Fig.6: Cross sectional view of stress distribution in Circular CFST Specimens.

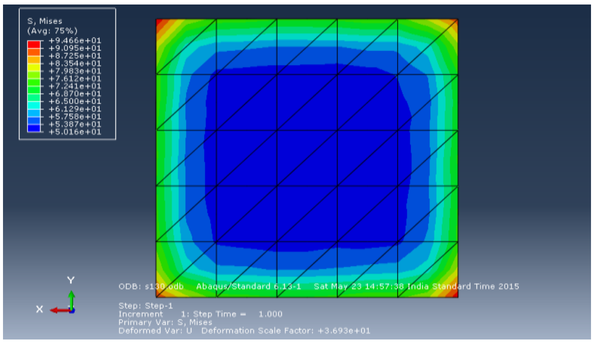

Fig.7: Cross sectional view of stress distribution in Square CFST Specimens

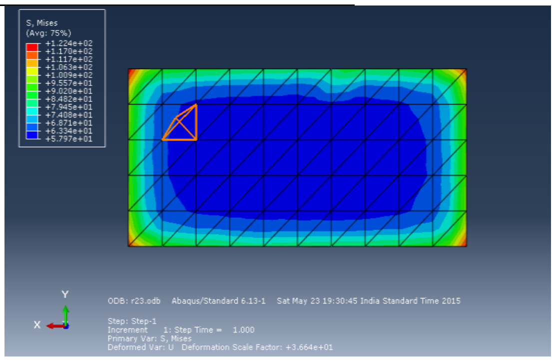

Fig.8: Cross sectional view of stress distribution in Rectangular CFST Specimens.

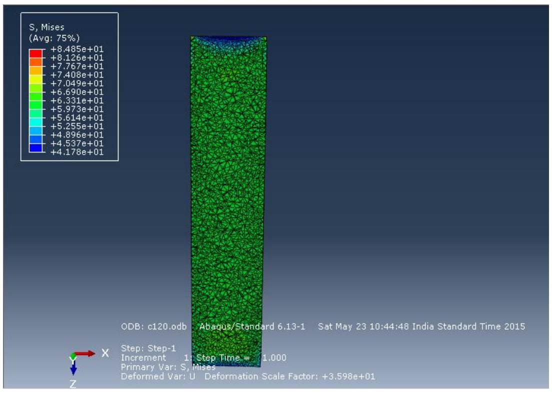

Fig.9: Mises stress distribution in CFST Specimens by taking vertical section.

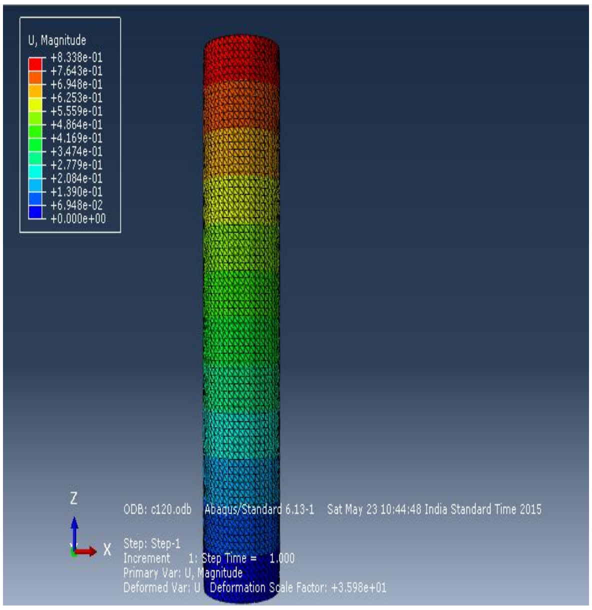

Fig.10: Displacement in vertical direction of Circular CFST specimens.

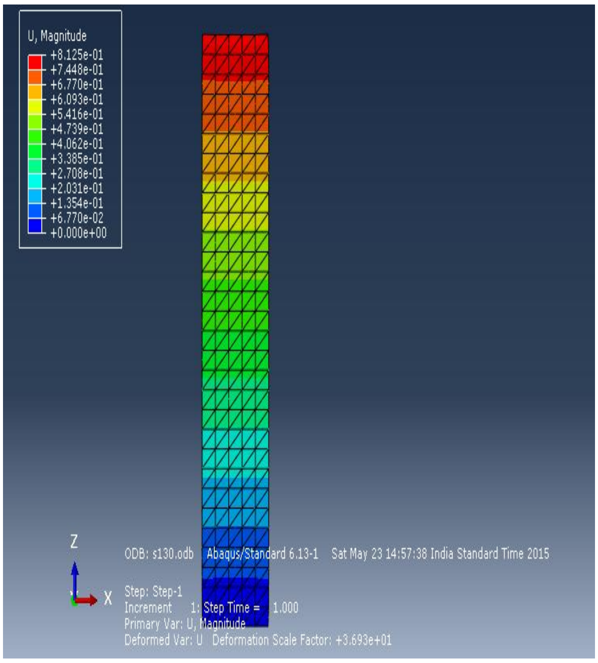

Fig.11: Displacement in vertical direction of Rectangular and Square CFST specimens.

CONCLUSION

1. Analytical results obtained by ABAQUS are in good agreement with experimental results and quite comparable with experimental results. However, non-linear analysis need to be made for further detailed investigation.

2. Due to confinement pressure of steel shell concrete take exhibits more strength. The stresses in steel tubes occurs 1.5 to 2.5 times than concrete which are observed from stress distribution diagram.

3. The confinement pressure is more effective for circular concrete filled steel tube sections than rectangular and square sections, because stress concentration at corners, which is also observed in stress distribution diagram.

4. The CFST specimens are failed due to local buckling. Circular specimens failed in length in upper half part while square and rectangular specimens fails at ends where they rest while testing.

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