

Study on Structural Behaviour of Concrete Filled Steel Tubular Columns with and without Shear Connectors

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ABSTRACT: This thesis is in the broad area of concrete filled steel tubular columns and to be terse, is on the study on influence of shear connectors on the behaviour of concrete filled steel tubular columns under concentric loading conditions. Concrete filled steel tubular (CFST) columns are a form of composite construction that comprise of concrete filled into a steel tube. The steel tube provides confinement to the concrete core which results in an increased concrete compressive strength and deformation capacity. In-fill materials help in increase the strength of composite columns. The shear connectors shall be capable of resisting the shear force between the concrete and the structural steel tube and at the same time prevent the vertical separation of the concrete from the structural steel tube. This thesis work further focuses on the influence of different cross-section of CFST columns (Circular, elliptical, triangular, rectangular, square and hexagonal) on ultimate load capacity, deflection stiffness and strain energy absorbed. The Finite element method is an analytical tool which is able to model composite structures and is able to calculate the non-linear behaviour of the structural members. In this project work CFST columns of different cross section are modelled using ANSYS 16 software and the experimental study is done on the selected case under concentric loading condition. The influence of spacing of shear connectors on the load-deflection behaviour of CFST columns are also studied.

KEYWORDS: CFST, Shear connectors, Circular, elliptical, triangular, rectangular, square, hexagonal, Load-deflection, stiffness, strain energy.

I. INTRODUCTION

This thesis is in the broad area of concrete filled steel tubular columns and to be terse, is on the study on influence of shear connectors on the behaviour of concrete filled steel tubular columns under concentric loading. Concrete filled steel tubular (hereafter CFST) columns are a form of composite type of construction that comprise of concrete filled into a steel tube. The steel tube gives confinement to the concrete core which results in increased concrete compressive strength and deformation capacity. In-fill materials help in increasing the strength of CFST columns.

The present study endeavour attempts to investigate the behaviour of concrete filled columns with and without shear connectors under loading conditions. Concrete filled steel tube columns are widely used in construction. This type of structural elements is favoured in practice because of its small cross sectional area to load carrying capacity ratio. Hence, mega concrete columns in tall buildings lower floors can be substituted by smaller sections of CFST columns. Therefore, such structural elements should be investigated better before it is used in critical structures. Thus, intensive parametric studies should be performed in order to fully understand the behaviour of CFST columns.

The behaviour of concrete-filled steel tubular columns can be simulated by modeling them in ANSYS or else experimenting them. Concrete filled steel tube (CFST) columns finds wide applicability in high rise buildings, in subway stations, they are used as electricity pylons, as bridge piers etc. Concrete filled steel tubes craves for augmenting fire resistant insulation if fire protection of the structure is critical. The CFST structures have good

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 5, Issue 7, July 2016

constructability as the steel tubes can be used as the formwork for casting concrete in construction. CFSTs provide better compressive and torsional resistance.

The FE method is an analytical tool which is able to model concrete filled tubular columns. FEM helps in the investigation of the behaviour of the concrete filled tubular columns of different cross sections under concentric loadings, load-deflection behaviour, strain energy absorbed and stiffness /compliance. The change in the behaviour of the CFT

columns with and without shear connectors is compared. Experimental studies were conducted on a selected case.

II. RELATED WORK

Paper on the load bearing capacity of concrete filled steel tube columns with and without shear connectors by Girigharan et al.[15](2015) observed the behaviour of CFST columns when shear connectors are used. The experimental studies conducted made them to a conclude that the load carrying capacity of CFST columns increased with the usage of shear connectors from 17.5% to 18.3%. Many literature works mentioned above were based on CFST columns. On the other hand, greater part of these investigations were on sections utilizing basic cross-sections of circular, square and rectangular ones. The other cross-section studies were found to be limited in number. Only limited number of literature works were available on axially loaded CFST segments with the presence of shear connectors. This paper exhibits the analytical study of different cross-sections namely circular, square, rectangular, hexagonal, elliptical and triangular with and without shear connectors. Experimental work of a selected case were also tested under axial load conditions.

III. SHEAR CONNECTORS

CFST columns were considered superior because of its greater strength due to its composite action. At beginning stage this composite action cannot be developed due to the expansion of steel was quite more than concrete. Interface bonding between the composites were reduced due to this reason. Thus, it reduces the strength and elastic stiffness of the CFST columns. To overcome this problem in the initial elastic stage, usage of shear connectors was used to reduce the lateral expansion of the concrete core and steel. The connectors shall be capable of resisting the shear force between the concrete and the structural steel tube. At the same time it prevents the vertical separation of the concrete from the structural steel tube. The shear connectors must be of the type which permit a better compaction of concrete to ensure that the entire surfaces are in contact with concrete. Bolts of High strength according to IS 1364-Part 1 (2002) is utilized shear connector.

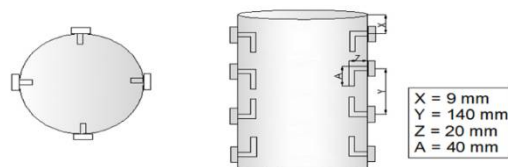


Fig. 1. Typical View of Shear Connectors

IV. OBJECTIVES OF THE PRESENT WORK

1. To study the influence of cross-section on strength, deflection, stiffness and strain energy absorbed by concrete filled steel tubular columns with and without shear connectors.
2. Determination of the influence of concentric loading on concrete filled steel tubular columns with and without shear connectors using ANSYS.
3. Experimental determination of load –deflection behaviour of selected case.
4. Discussion and conclusion of results

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

V. METHODOLOGY

1. Validation of finite element analysis of concrete filled steel tubular columns based on the study done by Girigharan and Ramakrishnan (2015) on paper titled, "Load bearing capacity of concrete filled steel tube columns with and without shear connectors".
2. Finite element analysis of CFST columns with and without shear connectors.
3. Experimental verification.
4. Interpretation of results.

VI. SCOPE OF PROJECT

The Scope of Work is as detailed below:-

1. Problem study & input data finalization
2. Concept study of CFST
3. FEM Analysis.
4. Project documentation with plots/sketches & result study observation

VII. ANALYTICAL STUDY

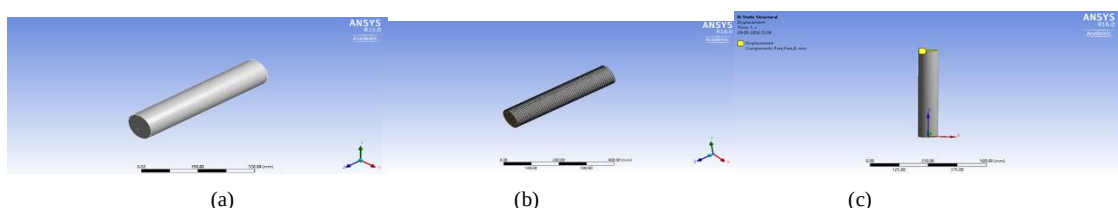
Six different cross-sections of concrete filled tubular columns with and without shear connectors (circular, triangular, rectangular, square, hexagonal and elliptical) under concentric loading was modelled using ANSYS 16. Solid 185 is used for modelling concrete core and steel tube and is defined by 8-nodes having 3-DOF at each node. It is having translation in the nodal x, y and z directions. The element has hyper elasticity, stress, stiffening, creep, plasticity, large deflection and large strain capabilities. The contact elements and target elements (CONTA 173 and TARGE 170) are laid on the parts of the model that are analysed for interaction. The coefficient of friction between concrete and steel is assumed to be 0.2. The columns are hinged at both ends and is concentrically loaded. It is free to rotate in all three directions at the loaded edges. The dimensions of the concrete filled steel tubes were taken fixing the area of cross-section as 6026.95 mm². The height of each specimen is 438 mm and the thickness is 1 mm

Table 1: Details of dimensions of specimen

Sl.No:	Specimen	Dimensions(mm)
1	Circular	Diameter = 87.6
2	Square	Side = 77.63
3	Rectangular	Length = 86.09 Breadth = 70
4	Triangular	Side = 117
5	Hexagonal	Side = 34.0571
6	Elliptical	Major axis = 50 Minor axis = 38.36

Material property of the geometry is defined when the model is transferred to "the setup" part in Ansys workbench. The column is made of concrete of M₃₀ grade concrete and steel tube of the column is made of Fe₂₅₀ grade steel. The material property is assigned by selecting the geometry of the assignment to the defined property. The meshing method used in the model is Hex Dominant method with relevance taken to zero.

VIII. CONCRETE FILLED TUBULAR COLUMNS WITHOUT SHEAR CONNECTORS



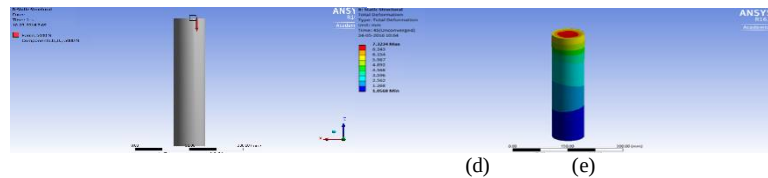


Fig. 2. (a) Model (b) Meshing (c) Support conditions (d) Loading diagram (e) Deformation diagram of circular concrete filled tubular columns without shear connectors.

Table 2: Result of test CFST specimens

SL.No	Specimen details	Ultimate load of CFST	Deflection at failure point of	Strain Energy
1	Circular	225	7.32	0.85
2	Triangular	220	4.5246	0.8
3	Rectangular	190	5.47	0.5
4	Square	175	2.82	0.35
5	Ellipse	170	2.5773	0.22
6	Hexagon	100	1.7929	0.07

IX. CONCRETE FILLED TUBULAR COLUMNS WITH SHEAR CONNECTORS

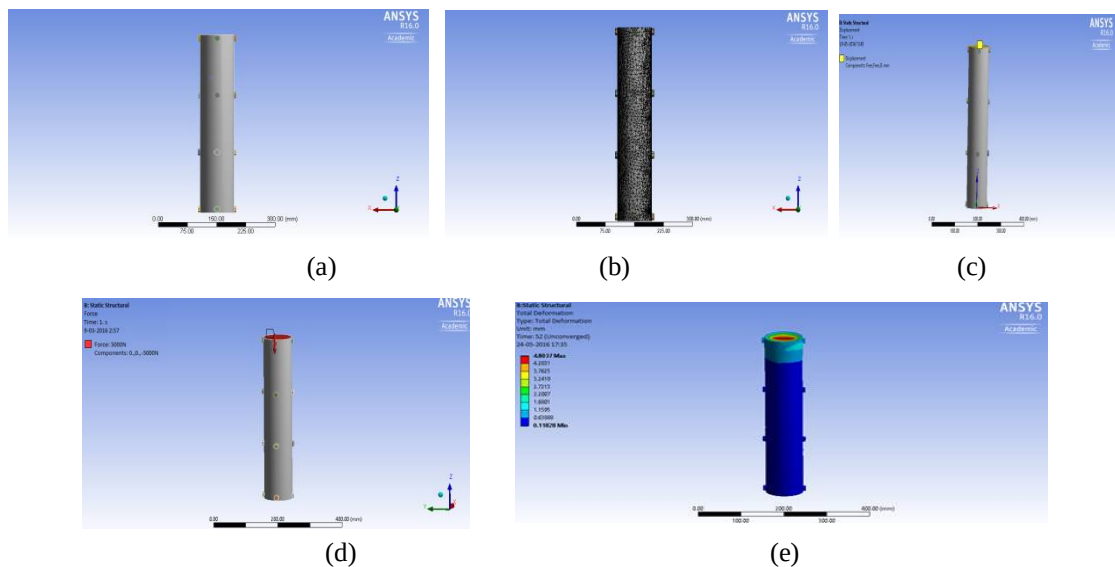


Fig. 3. (a) Model (b) Meshing (c) Support conditions (d) Loading diagram (e) Deformation diagram of circular concrete filled tubular columns with shear connectors.

Table 3: Result of test CFST-S specimens

SL.No	Specimen	Ultimate	Deflection	Strain
1	Circular	260	4.8037	0.65
2	Triangular	240	3.5324	0.5
3	Rectangular	225	4.279	0.45
4	Square	210	2.3594	0.25
5	Ellipse	200	1.237	0.15
6	Hexagon	120	1.5323	0.05

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

X. LOAD-DEFLECTION BEHAVIOUR OF CONCRETE FILLED STEEL TUBULAR COLUMNS

The analytical model was used to calculate ultimate loading capacity, stiffness and strain energy from the load – deflection behaviour of CFST columns of different cross-sections. The load – deflection behaviour shows that circular cross-section better loading capacity of 225 kN comparing all other cross-sections. The load carrying capacity of triangular cross-section was 220 kN which proved the efficiency to behave as a good CFST column. The maximum deflection at failure point was observed for circular CFST column i.e. 7.32 mm. Hexagonal cross-section showed least load carrying capacity of all other section i.e. 100 kN. The selected case of circular cross-section with maximum load carrying capacity was experimented.

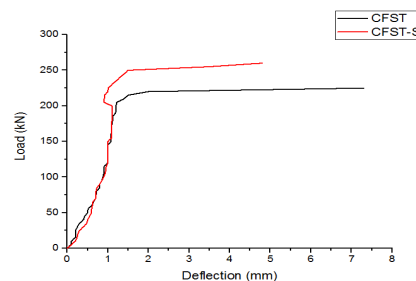


Fig. 4. Load-deflection diagram of circular concrete filled tubular columns with and without shear connectors

CFST-S = Concrete filled steel tubular column with shear connectors.

CFST = Concrete filled steel tubular column without shear connectors

Load carrying capacity increased about 17% by introducing shear connectors to the CFST columns and the deflection was reduced by about 35 % with the introduction of shear connectors. All the cross-sections showed increase in load carrying capacity and deflection was also reduced due to introduction of shear connectors. The load carrying capacity of circular cross-section increased to 260 kN and the deflection reduced to 4.83 mm which was clearly evident from the load-deflection behaviour of the section. The triangular cross –section increased to about 240 kN and deflection of 3.53 mm. The circle after reaching maximum load it deforms plastically i.e. ideal plastically. In triangle exhibits non-linear behaviour. Hexagonal and square column exhibits linear elastic and exhibits hardening. Elliptical and rectangular column in the beginning behaves linear elastically, then it behaves as ideal plastic. Hardening properties are more predominant in hexagonal and square columns.

XI. STIFFNESS (ELASTIC REGION)

Stiffness is defined as the rigidity of an object, the extent to which it resists deformation in response to an applied force. When an object is more flexible, less stiff it is. Elliptical concrete filled tubular column is less stiff. Compliance property of elliptical concrete filled steel tubular column seems to be higher than all other columns. The stiffness of circular cross-section was 166.66 kN/mm and 112.5 kN/mm for ones with shear connectors and without shear connectors which was found higher. The CFST column with shear connectors are having more stiffness comparing the other column.

XII. STRAIN ENERGY

The strain energy could be evaluated from the load deflection diagram and plotted. Plots were made for columns with circular cross –section with and without shear connectors. Introduction of shear connectors indicated a reduction factor of 0.75 in strain energy absorption capacity. Similar behaviour is observed in other cross-sections also.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

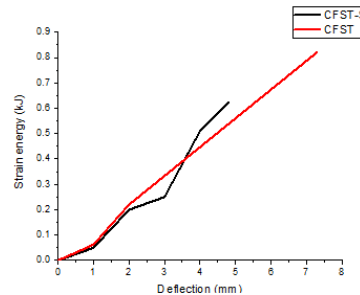


Fig.5. Strain energy v/s deflection for CFST column with and without shear connectors.

XIII. INFLUENCE OF SPACING OF SHEAR CONNECTORS

The influence of spacing for shear connectors were done so as to analyse the variation of load carrying capacity. When the spacing between shear connectors were increased from 80 mm to 140 mm, the load capacity were increased as shown in table 5.1. But for a spacing beyond 140 mm i.e. for 143 mm the ultimate load carrying capacity was dropped from 260 kN to 200kN. Efficient spacing for a CFST column of height 438 mm seems to be 140 mm and experimented specimen with same specimen showed comparable results. The spacing check of 80 mm, 100mm, 120 mm, 140 mm and 143 mm were analysed in ANSYS.

Table 4. Ultimate load capacity of various spacing of shear connectors

Sl.no:	Spacing(mm)	Ultimate load carrying capacity(kN)
1	80	110
2	100	170
3	120	180
4	140	260
5	143	200

XIV. PROPERTIES OF MATERIAL USED

Circular concrete filled tubular columns have an advantage over all other sections when used as compression member for a given cross-sectional area which was finalized from the numerical study. Circular CFST's have better load carrying capacity than all other cross sections with much less deflection. They do have very large uniform flexural stiffness in all directions.

The mix ratio calculated for casting purpose is 1:1.8:2.18:0.45.

Specimen Details

For the test procedure 2 types of specimen are casted and they are explained below.

- Circular concrete filled steel tube without shear connectors.
- Circular concrete filled steel tube with shear connectors

Specification of specimen :-

Length of steel tube	: 438 mm
Diameter of steel tube	: 87.6 mm
Shear connector	: M 8 bolt
Length of shear connector	: 60 mm
Thickness of steel tube	: 1 mm
Spacing of shear connectors	: 140 mm

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

XV. EXPERIMENTAL INVESTIGATION

Mix proportion for M 30 grade concrete was prepared according to IS 10262:2009 concrete mix proportioning – guidelines. The following table shows the mix proportion for M 30 grade concrete

Table.5. Mix proportion of M30 concrete

Sl.No	Material	Amount of materials
1	Cement(kg/m ³)	437.77
2	Fine aggregate(kg/m ³)	828.414
3	Coarse aggregate(kg/m ³)	954.477
4	Admixture Sikament 170-1(ml)	8.74
5	Water –cement ratio	0.45

Mix ratio of M₃₀ grade concrete obtained was 1:1.8:2.18:0.02 with water cement ratio of 0.45. The size of coarse aggregate used for M 30 concrete was 20 ,The required steel tube were purchased from local market to fabricate the column. For experiment the steel tube was cut into required length of 438 mm by grinding machine. The diameter of the steel tube was 87.6 mm and its thickness was 1 mm. The holes were drilled using drilling machine at appropriate points and the shear connectors were inserted and the properly welded. The shear connectors were M 8 bolt having a diameter of 8mm and a length of 60 mm. It was bent at a distance of 20 mm at lathe. The shear connectors were placed at 140 mm spacing.



Fig.6. Steel tube with shear connectors before filling concrete

All specimens were tested in Universal testing machine having load capacity of 1000kN. The column were tested under axial loading .Deflection meter were fixed at the bottom part of the UTM axially to measure deflection with respect to the applied load. Load was applied axially to the column at an increment of 5 kN. For each load increment the deformations were recorded. All specimens were subjected to load up to failure. The load was applied gradually till the ultimate load and the deflections were measured at various load stages. The following fig shows test setup of column.



Fig.7. Test setup of column

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

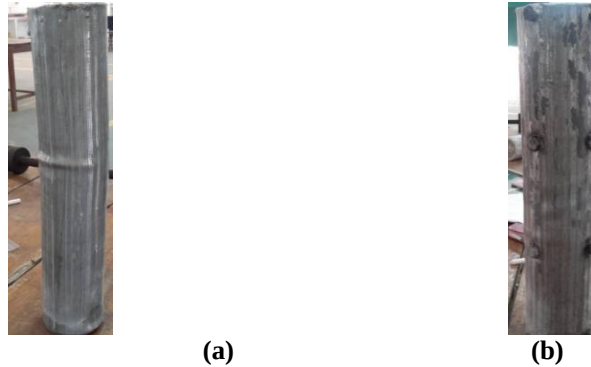


Fig 8.(a) Deformed shape of column without shear connectors (b) Deformed shape of column with shear connector

Table.6. Test results of column

Specimens	Ultimate load(kN)	Ultimate axial deflection(mm)
Concrete filled steel tubular column without shear connectors	233	12.2
Concrete filled steel tubular column with shear connectors	272	6.3

XVI. STRAIN ENERGY

Strain energy of the experimental model were calculated. The showed circular cross-section without shear connectors showed maximum strain energy of 1.35 kJ than the CFST with shear connectors .The reduction factor in case of strain energy was found to be 0.62.This showed comparable results with the analytical model as well.

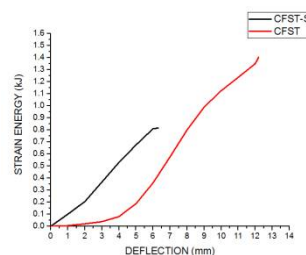


Fig.9.Strain energy –deflection for Circular CFST columns with and without shear connectors

XVII. CONCLUSIONS

The paper presents the study of analytical behaviour of concrete filled steel tubular columns of different cross-sections with and without shear connectors (circle, triangle,rectangle,square,ellipse and hexagon) using ANSYS. Experiments were also conducted selecting circular type with and without shear connectors. The paper presents mainly the study of short concrete filled tubular columns under axial compression .The axial load capacity of CFST columns with concrete of compressive strength 30 Mpa have been studied. The steel tube used was of grade Fe 250.The proposed study comprised the evaluation of ultimate axial load capacity The proposed study can be used to predict the ultimate axial load capacity of CFST column of six cross-sections, stiffness/ compliance, strain energies (toughness) . The influence of spacing of shear connectors have also been included in this study. The following observations are made from the study as:-

- The ultimate load capacity of circular CFST is found higher compared to all other cross-sections for about 2-8%.
- The influence of shear connectors increased the load carrying capacity to about 17% of those without shear connectors in the case of circular CFST sections. At the same time deformation capacity is found reduced by 35%.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

- c) The effect of shear connector spacing is studied analytically. The influence of shear connectors spacing on ultimate load capacity is indicated in figure 5.1. The figure shows maximum ultimate load capacity with a spacing of 140 mm.
- d) Circular CFST without shear connectors has higher strain energy absorption capacity of 32 % more than circular CFST with shear connectors.
- e) The stiffness of circular CFST with shear connectors increased by 32% for those without shear connectors. Stiffness of various CFST columns were presented in the form of bar charts as a design information.
- f) The experimental study using circular CFST with and without shear connectors showed comparable results with those obtained in analytical studies.

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