Structural Behavior of Concrete-Filled Steel Tube Long Columns Stiffened by External and Internal Continuous Spirals

Smrithi S, Parvathy Anand Menon

Abstract— Concrete filled steel tubes (CFST) are composite members consisting of a steel tube infilled with concrete. CFST long columns are increasingly used in high-rise buildings and in large span structures inorder to provide axial strength and stiffness. This paper investigates the behavior of concrete filled steel tube long columns stiffened by external and internal spiral reinforcement. Numerical models were developed using ANSYS and structural behavior of CFST long columns strengthened by external and internal continuous spirals were analysed. Specimens were stiffened as (1) external continuous spiral (ECS) welded to the exterior surface of the steel tube, (2) internal continuous spiral (ICS) welded to the interior surface of the steel tube. The main parameters in this study are steel tube thickness, diameter of spiral bar, the number of spiral turns and location of the continuous spirals. A comparative study was done on CFST and reinforced concrete filled steel tube (RCFST) columns. Structural behavior of CFST long columns under eccentric loading is also analysed. Finite element analysis has been done to obtain the most effective specimen. The result shows that as steel tube thickness, spiral bar diameter and number of spiral turns increases load carrying capacity increases than the control specimen. It can be interpreted from the results that CFST specimens stiffened by internal continuous spirals have better load carrying capacity than the other specimens.

Index Terms— Biaxial eccentric loading, Concrete filled steel tube, External continuous spiral, Internal continuous spiral, Load carrying capacity, Reinforced concrete filled steel tube, Uniaxial eccentric loading.

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1 Introduction

Concrete filled steel tube (CFST) columns are very effective compression members in structures including bridges, buildings and piled foundations. They exhibit excellent structural and constructional advantages, such as high strength, fire resistance, large stiffness and eliminating the need of formwork. The steel tube provides transverse reinforcement to the core concrete, where as the core concrete delays the local and overall buckling of steel tubes. Studies have shown that a circular cross-section provides the best confinement to the core concrete compared to rectangular and square sections [1]. In CFST columns there will be an imperfect interface bonding between concrete and steel in the elastic loading phase. This is the main disadvantage of CFST columns. Inorder to avoid this spiral reinforcement is provided. Continuous spirals provide uniform confining pressure and confinement effect along entire length.

Lai and Ho [6] studied the effect of external continuous spirals on uni-axial strength and ductility of CFST columns. Compression capacities of thirty-eight specimens were tested using different diameters and different spacing. It shows that continuous spirals increases the initial stiffness, strength, ductility and the interface bonding. Salih K and Talha [9] studied the effect of external and internal continuous spirals on axial compressive loading on CFST short columns. Sixteen specimens were tested by changing the diameter and number of turns of spirals. Spirals limited the lateral deformation of steel tubes and core concretes and enhanced the imperfect interface bonding.

There is only one research in the literature studying the effect of CFST short columns stiffened by external and internal continuous spirals. There is no previous study investigating the behavior of continuous spirals on CFST long columns. This study aims to analyse the structural behavior of CFST long columns stiffened by welded ECS and ICS. To analyse the behavior of long columns, thirty eight specimens were tested under compressive loading and the results are compared with control specimen. To determine the stiffness and efficiency, a comparison of CFST specimens with spiral reinforcement and reinforced CFST specimens is done. Finally, the behavior of CFST long columns with spiral reinforcement were analysed under eccentric loading condition.

2 Finite Element Analysis

Salih K. Alrebeh, Talha Ekmekyapar (2019) was selected for validation. CFST specimen stiffened by internal continuous spiral with 8mm diameter spiral and 7 turns having a spacing of 36mm is selected. Outer diameter of steel tube is 114.3mm and total length 320mm. Finite element modelling is done using ANSYS 16 software. Model of the CFST column and corresponding deformation is shown in fig. 1 and fig. 2. The result obtained from the model is shown in fig. 3. The results obtained from the model developed and the paper is compared and 7.1% error was obtained during validation.

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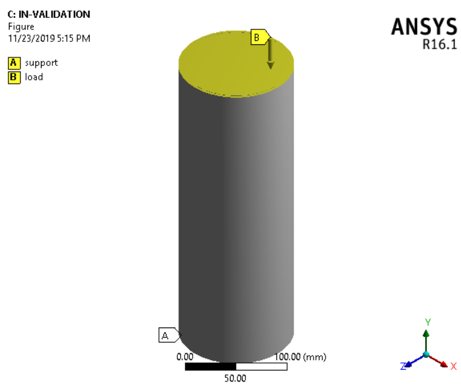

Fig. 1. Boundary conditions applied to CFST column

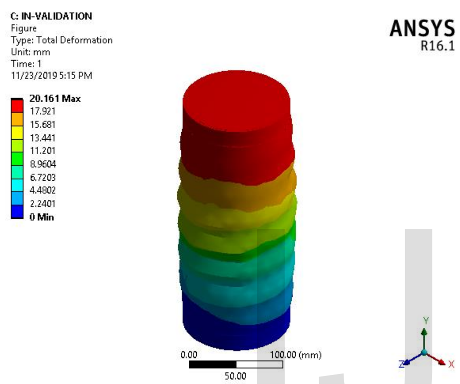

Fig. 2. Failure mode of CFST columns stiffened by ICS

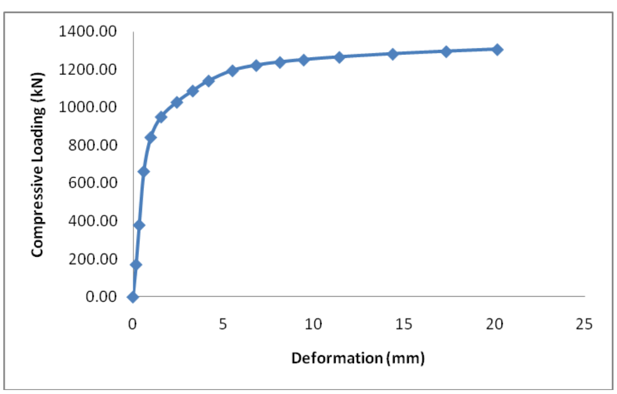

Fig. 3. Load deformation response of CFST specimen stiffened by ICS.

3 Parametric Study

3.1 Details of test specimens

In order to evaluate the uniaxial behavior of CFST columns, thirty eight specimens were modelled and analysed under axial loading. The specimens are grouped according to the location of continuous spiral (external and internal), thickness of steel tube (3.21, 5.8mm), diameter of spiral bar (6, 8, 10mm), number of spiral turns (30, 50, 70). The specimens are stiffened as ECS which is welded to the external surface of the steel tube and as ICS which is welded to the internal surface of the steel tube. The columns are subjected to axial compressive loading. Bottom end is assigned as fixed. The details of the specimens are shown in table 2 and table 3. The column specimens modelled using ANSYS with ECS is shown in fig. 4 and columns with ICS are shown in fig. 5.

The naming system provided for distinguishing CFST specimens has five parts: specimen type, spiral location, diameter of spiral (6, 8, 10mm), number of spiral turns (30, 50, 70) and thickness of steel tube (3.21, 5.8mm). Letter C denotes the CFST specimen. Symbols ES denotes for external spiral and IS denotes for internal spiral. For example, (C-ES-10-30-3.21) represents a CFST specimen confined by external spiral (denoted by the second part "ES") with diameter of 10mm (denoted by the third part "10") and thirty turns (denoted by fourth part "30") having a tube thickness of 3.21mm (denoted by fifth part "3.21"). The control CFST column (without external and internal spiral) was represented by C-SO.

3.2 Material properties

All specimens have the same dimensions with outer steel tube thickness 114.3mm; total length of the specimen is 3000mm. Properties of concrete is shown in table 1. The yield strength of steel tube and spiral reinforcement is 380MPa and 350MPa. Young's modulus and poisson's ratio is selected as per IS 456-2000 [21]. At each end of the test specimen a small distance of 20mm is provided free.

TABLE 1
Properties of Concrete

Density	2338.27kg/m³
Compressive strength	41.0MPa
Young's modulus	32015.62MPa
Poisson's ratio	0.15

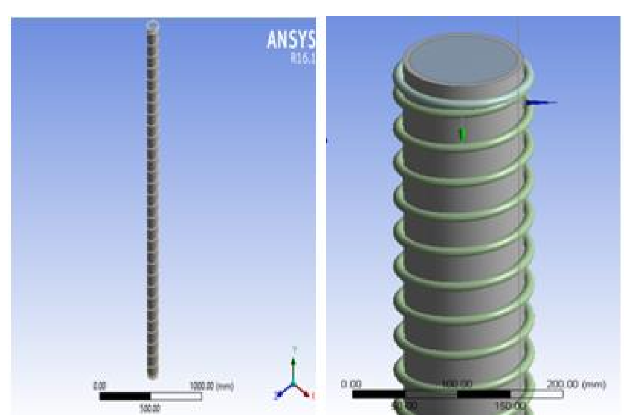

Fig. 4. CFST long column with external continuous spiral.

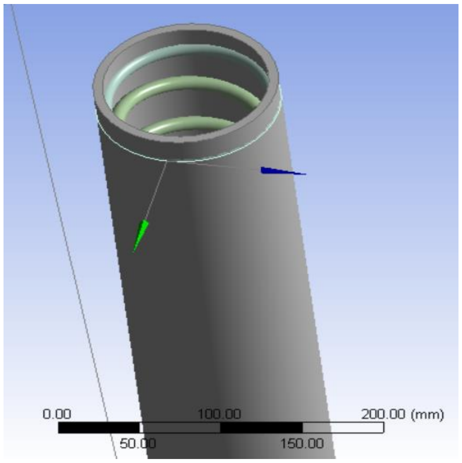

Fig. 5. CFST long column with internal continuous spiral.

TABLE 2
DETAILS OF CFST SPECIMENS WITH ECS

Specimen details	Spiral diameter (mm)	No.of spiral turns	Ultimate load (kN)	Improvement ratio (%)
C-SO-3.21	-	-	807.6	-
C-ES-6-30-3.21	6	30	810.3	0.33
C-ES-6-50-3.21	6	50	815.6	0.99
C-ES-6-70-3.21	6	70	847.1	4.89
C-ES-8-30-3.21	8	30	878.4	8.77
C-ES-8-50-3.21	8	50	939.8	16.36
C-ES-8-70-3.21	8	70	995	23.2
C-ES-10-30-3.21	10	30	894.3	10.74
C-ES-10-50-3.21	10	50	958.3	18.66
C-ES-10-70-3.21	10	70	1024.6	26.87
C-SO-5.8	-	-	1099	-
C-ES-6-30-5.8	6	30	1220.7	11.07
C-ES-6-50-5.8	6	50	1283	16.74
C-ES-6-70-5.8	6	70	1309	19.1
C-ES-8-30-5.8	8	30	1299.7	18.26
C-ES-8-50-5.8	8	50	1306.9	18.91
C-ES-8-70-5.8	8	70	1310	19.2
C-ES-10-30-5.8	10	30	1304.2	18.67
C-ES-10-50-5.8	10	50	1308	19.01
C-ES-10-70-5.8	10	70	1506	37.03

Table 2 and table 3 summarize the load carrying capacities of CFST long columns stiffened by external and internal continuous spirals. Ultimate load carrying capacity increases with the increase of steel tube thickness, diameter of spiral bars and number of spiral turns. From table 2, C-ES-8-70-3.21 and C-ES-8-70-5.8 has more load carrying capacity than C-ES-10-50-3.21 and C-ES-10-50-5.8. From table 3, C-IS-8-70-3.21 and C-IS-8-70-5.8 has more load carrying capacity than C-IS-10-50-3.21 and

TABLE 3
DETAILS OF CFST SPECIMENS WITH ICS

Specimen details	Spiral diameter (mm)	No.of spiral turns	Ultimate load (kN)	Improvement ratio (%)
C-SO-3.21	-	-	807.6	-
C-IS-6-30-3.21	6	30	818.5	1.35
C-IS-6-50-3.21	6	50	984.5	21.9
C-IS-6-70-3.21	6	70	1022.7	26.63
C-IS-8-30-3.21	8	30	907.3	12.34
C-IS-8-50-3.21	8	50	995.7	23.29
C-IS-8-70-3.21	8	70	1030	27.53
C-IS-10-30-3.21	10	30	910.9	12.79
C-IS-10-50-3.21	10	50	1017	25.92
C-IS-10-70-3.21	10	70	1031.3	27.67
C-SO-5.8	-	-	1099	-
C-IS-6-30-5.8	6	30	1310.2	19.21
C-IS-6-50-5.8	6	50	1381	25.65
C-IS-6-70-5.8	6	70	1417	28.93
C-IS-8-30-5.8	8	30	1313.1	19.48
C-IS-8-50-5.8	8	50	1407	28.02
C-IS-8-70-5.8	8	70	1439	30.93
C-IS-10-30-5.8	10	30	1316.8	19.82
C-IS-10-50-5.8	10	50	1419	29.12
C-IS-10-70-5.8	10	70	1513	37.67

C-IS-10-50-5.8. Load carrying capacity increases with increase in spiral turns rather than increasing the diameter of spiral bars. In practical case, choosing 8mm diameter spiral bar will be more effective. It has more load carrying capacity than 6mm diameter spiral and flexibility than 10mm diameter spiral. Choosing smaller diameter spiral with increased spiral turns will be more effective. The effective model of CFST long columns with external and internal continuous spirals is C-ES-8-70-5.8 and C-IS-8-70-5.8.

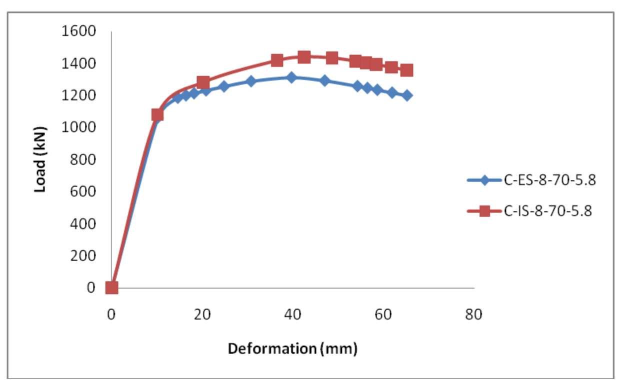

Fig. 6. Comparison graph of CFST specimens with ECS and ICS.

The effective models from the parametric study are compared. Fig. 6 shows the comparison of CFST long columns with ECS and ICS. Here load carrying capacity is more for CFST long column stiffened by internal continuous spirals.

4 Comparison of CFST and RCFST Specimens

4.1 RCFST Specimen details

Reinforced concrete filled steel tube (RCFST) column consists of a hollow steel tube filled with concrete which is reinforced with steel bars. RCFST structures are developed mainly on the purpose of combining the merits of RC and CFST structures. Reinforcement consists of longitudinal steel bars and transverse ties throughout the length to connect the longitudinal bars. Material properties of steel tube and concrete are as same as for columns with ECS and ICS. The effective models of CFST long columns stiffened by ECS and ICS from parametric study is selected for the comparison. Outer diameter of the steel tube is 114.3mm. Due to the small diameter of the steel tube, the tied type was used as transverse reinforcement. Four longitudinal steel-bars with diameter of 12mm and diameter of closed ties are 6mm with 56mm spacing between ties is shown in fig. 7. It is subjected to axial compressive loading. Bottom end is assigned as fixed.

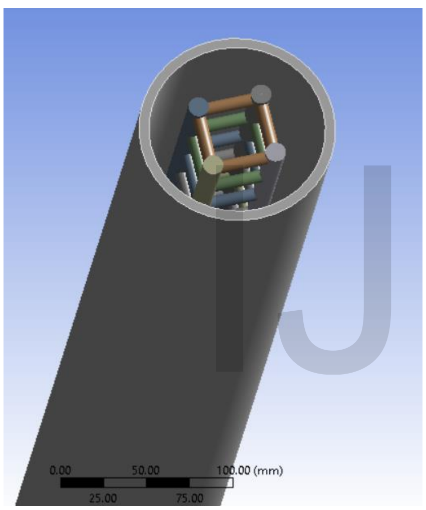

Fig. 7. Model of RCFST specimen

TABLE 4
PROPERTIES OF RCFST SPECIMENS

Specimens	Tube thickness (mm)	Ultimate load (kN)
RC-3.21	3.21	669.36
RC-5.8	5.8	884.92

The specimen naming system includes the specimen type and thickness of steel tube. Symbol RC denotes for reinforced CFST specimen. Ultimate load carrying capacity is determined for specimens with varying tube thickness. The results obtained are shown in table 4. From table RC-5.8 has more ultimate load carrying capacity. Here as thickness of steel tube increases, load carrying capacity increases.

4.2 Comparison of results

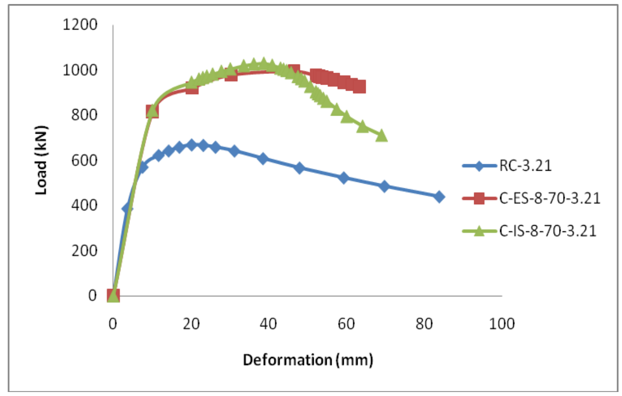

Fig. 8. Load deformation graph showing comparison of specimens with 3.21mm tube thickness.

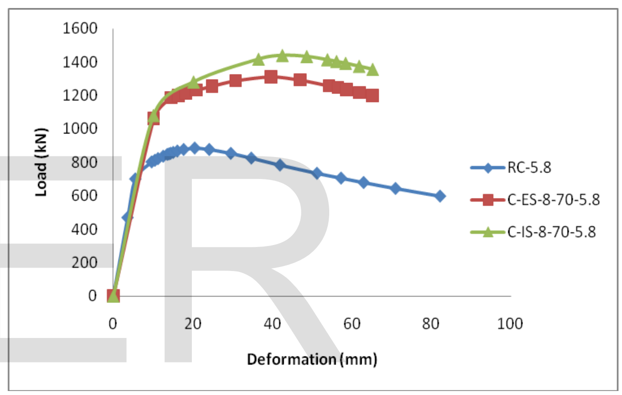

Fig. 9. Load deformation graph showing comparison of specimens with 5.8mm tube thickness.

From graph (fig.8 and fig.9) CFST specimens with spiral reinforcement has more load carrying capacity and stiffness than RCFST specimens. CFST columns with ICS have more ultimate load carrying capacity than RCFST and CFST columns with ECS. From the comparison study, specimens C-IS-8-70-3.21 have 53.8% and C-IS-8-70-5.8 has 62.6% more load carrying capacity as compared with RCFST specimens.

5 Compression Under Eccentric Loading

Twelve CFST long columns were subjected to compression under eccentric loading. Six specimens were analysed under uniaxial eccentric loading and six specimens under biaxial eccentric loading. The effective model from the parametric study is selected for eccentric loading. In a uniaxial eccentrically loaded column, the load is acting at a distance e_x in the x axis. In a biaxial eccentrically loaded column, the load is acting at a distance e_x in the x axis and e_y in the y axis. Fig. 10 shows the uniaxial and biaxial eccentric loading on column. Behavior of columns under 14.28 and 28.57mm eccentricity is analysed.

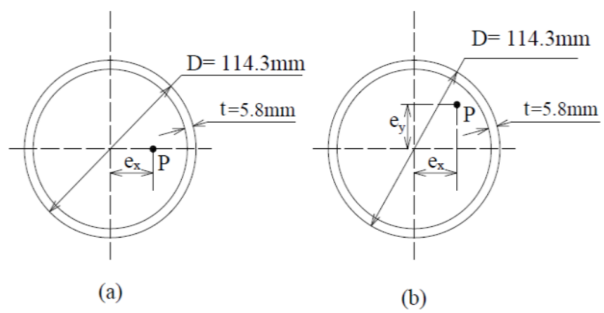

Fig. 10. Eccentric loading.(a)Uniaxial eccentricity and (b)Biaxial eccentricity.

TABLE 5
UNIAXIAL ECCENTRIC LOADING RESULTS

Specimens	e_x (mm)	Eccentric load (kN)	Improvement ratio (%)
C-SO-U14.28	14.28	886.74	-
C-ES-U14.28	14.28	901.55	1.67
C-IS-U14.28	14.28	924.05	4.21
C-SO-U28.57	28.57	460.88	-
C-ES-U28.57	28.57	486.6	5.58
C-IS-U28.57	28.57	494.49	7.29

TABLE 6
BIAXIAL ECCENTRIC LOADING RESULTS

Specimens	e_x (mm)	e_y (mm)	Eccentric load (kN)	Improvement ratio (%)
C-SO-B14.28	14.28	14.28	498.6	-
C-ES-B14.28	14.28	14.28	517.08	3.71
C-IS-B14.28	14.28	14.28	524.3	5.15
C-SO-B28.57	28.57	28.57	419.88	-
C-ES-B28.57	28.57	28.57	441.61	5.17
C-IS-B28.57	28.57	28.57	447.78	6.64

Table 5 and table 6 shows the results of CFST columns under uniaxial and biaxial eccentric loading. Load carrying capacity of CFST long columns with continuous spiral reinforcement is compared with control specimens. Load carrying capacity is more for CFST long columns stiffened by continuous spirals than CFST long columns without spiral reinforcement. For CFST long columns stiffened by external and internal continuous spirals load carrying capacity reduced for eccentric loading than axial loading. As the distance from central axis increases load carrying capacity decreases in both uniaxial and biaxial eccentric loading. In case of uniaxial and biaxial eccentricity load carrying capacity is more for CFST long columns stiffened by internal continuous spirals.

6 CONCLUSION

Structural behavior of concrete filled steel tube columns with external and internal spiral reinforcement under axial and eccentric loading conditions are analysed using ANSYS software. A parametric study was conducted on the factors such as location of continuous spiral reinforcement, thickness of the steel tube, spiral bar diameter, number of spiral turns, and also a comparative study with RCFST columns and came to the following conclusions.

- The ultimate load carrying capacity of columns with external and internal continuous spiral improves as compared to control specimens.
- Parametric study results indicates that the load carrying capacity of CFST columns is improved significantly as a result of increasing the steel tube thickness, number of spiral turns and spiral bar diameter.
- Load carrying capacity is more for columns with smaller diameter spirals with increased number of spiral turns. Choosing such specimens will be more effective.
- Internal continuous spiral specimens have better load carrying capacity than external continuous spiral specimens and this is due to ICS increases the bond between steel tube and core concrete interfaces and increases the buckling resistance of steel tube during the elastic loading phase.
- Based on the findings load carrying capacity is more for CFST columns with continuous spiral reinforcement than RCFST columns.
- Stiffness is more for specimens with ECS and ICS than RCFST specimens.
- The load carrying capacity is reduced in case of eccentric loading than axial loading.
- In case of uniaxial and biaxial eccentric loading, load carrying capacity is more for columns stiffened by internal continuous spirals than columns stiffened by external continuous spirals.
- From this study it can be concluded that CFST columns stiffened by ICS is the best model.
- The only reason for the failure of CFST long column specimens is due to global buckling.

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