Enhancement of Load Carrying Capacity of Steel Tubular Columns In-filled with Fibre Reinforced Concrete

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Abstract--- *Steel members have the advantages of high tensile strength and ductility, while concrete members have the advantages of high compressive strength and stiffness. Steel - Concrete composite members, resulting in a member that has the valuable qualities of materials. In this paper, an attempt was made with steel tubular columns in-filled with fibre reinforced concrete and normal conventional concrete so as to improve the strength of tubular columns in construction works. The performance of circular and square concrete-filled steel tubular sections (CFSTs) with and without fibre under axial load is presented. The effects of steel tube dimensions, shapes and the strength of concrete are examined. Recorded column strengths are compared with the values predicted by Eurocode 4. 12 specimens were tested with strength of concrete as 20 MPa and a D/t ratio 22.3, 23.7 & 25.4. The columns were 76.1 & 88.9 mm in diameter and 72.0 & 91.5 mm in square are 900 mm in length. From the test results it was observed that the load carrying capacity of steel tubular columns in-filled with fibre reinforced concrete is greater than the conventional concrete. Eurocode 4 predicts the best estimation for CFST sections both conventional and fibre reinforced concrete columns. Hence this investigation would give a solution for effective application of fibre reinforced concrete in steel tubular sections to increase the load carrying capacity.*

Keywords--- *Composite, Columns, Steel Tubular Sections, Fibre Reinforced Concrete.*

I. Introduction

The two main types of composite column are the steel-reinforcement concrete column, which consists of a steel section encased in reinforced or unreinforced concrete, and the concrete-filled steel tubular (CFST) columns, which consists of a steel tube filled with concrete. CFST columns have several advantages over steel-reinforcement concrete columns. The main benefits of concrete filled columns are:

- Steel column acts as long-lasting and important formwork
- The steel column provides exterior reinforcement, and
- The steel column supports various levels of construction preceding to concrete being pumped.

Although CFST columns are suitable for all tall buildings in high seismic regions, their use has been limited due to a lack of information about the true strength and the inelastic behaviour of CFST members. Due to the traditional

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separation between structural steel and reinforced concrete design, the procedure for the designing CFST column using the American Concrete Institute's (ACI) code is quite different from the Load and Resistance Factor Design (LRFD) method suggested by the American Institute of Steel Construction's (AISC).

Notation

- D outside dimension of column
- t wall thickness of steel tube
- L length of the column
- P_{ue} measured ultimate load of the column
- f_y yield strength of steel
- f_{cc} characteristics cube compressive strength of concrete
- f_{cr} flexural strength of concrete
- f_{ct} split tensile strength of concrete

Concrete Filled Steel Tubular Sections

Circular tubular columns have an advantage over sections when used in compression members, for a given cross-sectional area, they have a large uniform flexural stiffness in all directions. Filling the tube with concrete will increase the ultimate strength of the member without significant increase in cost. The main effect of concrete is that it delays the local buckling of the tube wall and the concrete itself, in the restrained state, is able to sustain higher stresses and strains that when is unrestrained.

The use of CFSTs provides large saving in cost by increasing the floor area by a reduction in the required cross-section size. It is very important in the design of high rise buildings in towns where the cost of leasing spaces are extremely high. These are particularly significant in the lower storey of tall buildings where short columns usually exist. Concrete Filled Steel Tubular sections can provide an outstanding monotonic and seismic resistance in two orthogonal directions. Adopting numerous bays of composite CFST framing in each primary direction of a low to medium-rise building provides seismic redundancy while taking full advantages of the two way framing capabilities of CFSTs [1].

Past Research

Experimental research on CFST columns has been ongoing worldwide for many decades, with significant contribution having been made particularly by researchers in Australia, Europe and Asia. The huge volume of these experiments have been on moderate scale specimens (less than 200mm in diameter) using normal and high-strength concrete.

Neogi et al. [2] investigated numerically the elasto-plastic behaviour of pin-ended, CFST columns loaded either concentrically or eccentrically about one axis. It was assumed complete interaction between the steel and concrete, triaxial and biaxial effects were not considered. Eighteen eccentric loaded columns were tested, in order to compare the experimental results with the numerical solutions. The conclusions were that there was a good agreement between the experimental and theoretical behaviour of columns with L/D ratios greater than 15, inferred that triaxial effects were small for such columns. Where for columns with smaller L/D ratios, it showed some gain in strength due to triaxial effect.

A sequence of tests had been carried out by O'Shea and Bridge [3] on the behaviour of circular thin-walled steel tubes. The steel tubes had diameter to thickness D/t ranging between 55 and 200. The tests comprised; bare steel tubes, tubes with un-bonded concrete with only the steel section loaded, tubes with concrete in-filled with the steel and concrete loaded simultaneously and tubes with the concrete infill loaded alone. The results were compared to strength models in design standards and specifications. The results from the tests showed that the concrete infill for the thin-walled circular steel tubes has little effects on the local buckling strength of the steel tubes. However, O'Shea and Bridge [4] found that concrete infill can improve the local buckling strength for rectangular and square sections. Increased strength due to confinement of high-strength concrete can be obtained only if the concrete is loaded and the steel is not bonded to the concrete. For steel tubular sections with a D/t ratio >55 and filled with 120 MPa HSC, the steel tubes provide trivial confinement to the concrete when both the steel and concrete are loaded concurrently. Therefore, they considered that the strength of these sections can be estimated using Eurocode 4 with confinement ignored.

The influence of local buckling on behaviour of short circular thin-walled CFSTs has been examined by O'Shea and Bridge [4]. Two likely failure manners of the steel tube had been recognized, local buckling and yield failure. These were found to be independent of the diameter to wall thickness ratio. Instead, bond between the steel and concrete infill determined the failure mode. A suggested design method has been recommended based upon the endorsements in Eurocode 4 [5].

Kilpatrick et al [6,7] examined the applicability of the Eurocode 4 for design of CFSTs which use high-strength concrete and compare 146 columns from six different investigations with Eurocode 4. The concrete strength of columns ranged from 20 to 100 MPa. The mean ratio of measured / predicted column strength was 1.10 with a standard deviation of 0.13. The Eurocode safely predicted the failure load in 73% of the column analyzed.

Brauns [8] stated that the effect of confinement exists at high stress level when structural steel acts in tension and concrete in compression and that the ultimate limit state material strength was not attained for all parts simultaneously. In his study, the beginning of constitutive relationships for material components, the stress state in composite columns was determined taking into account the dependence of the modulus of elasticity and Poisson's ratio on the stress level in concrete.

O'Shea and Bridge [9] tried to estimate the strength of CFSTs under different loading condition with small eccentricities. All the specimens were short with a length-to-diameter ratio of 3.5 and a diameter to thickness ratio between 60 and 220. The interior concrete had a compressive strength of 50, 80 and 120 MPa. From those experiments O'Shea and Bridge concluded that the degree of confinement offered by a thin-walled circular steel tube to the internal concrete is dependent upon the loading condition. The highest concrete confinement occurs for axially loaded thin-walled steel with only the concrete loaded and the steel tube used as pure circumferential restraints. EC4 has been exposed to provide the best method for estimating the strength of circular CFSTs with the concrete and steel loaded concurrently.

For axially loaded thin-walled steel tubular sections, local buckling of the steel tubes does not occur if there is sufficient bond between the steel and concrete. For concrete strength up to 80 MPa, EC4 can be used with no reduction for local buckling. For concrete strength in excess 80 MPa, EC4 can still be used but with no enhancement of the internal concrete confinement and no reduction in the steel strength from local buckling and biaxial effects from confinement. Thin-walled circular axial compression and moment can be designed using the Eurocode 4 with no reduction for local buckling.

Test Specimens

A total of twelve specimens of Circular (designated C) and Square (designated S) sections were tested for this study. The column specimens were categorized into three different groups. Each group consists of four specimens filled with plain concrete (designated PC), fibre reinforced concrete (designated FRC) and the rest of the column specimens were tested as hollow sections for comparison (designated HS).

All the specimen properties and measured test results are given in Table 1. All the specimens were casted from square and circular hollow steel tubes and filled with two kinds of concrete. The average values of yield strength and maximum tensile strength for the steel tubular section were found to be 260 and 320 MPa respectively. The modulus of elasticity was calculated to be 2.0 x 10^5 MPa. In the present experimental work, the parameters of the test specimens are the shape of specimen, size of specimen, strength of concrete and D/t ratio of columns. All the selected parameters are within the ranges of practical limits.

Table 1: Specimen Properties and Ultimate Loads

Reference	D (mm)	t (mm)	D/t	L (mm)	L/D	f_y (Mpa)	f_{cu}(Mpa)	P_{ue}	Eurocode 4
C1-HS	76.1	3.2	23.7	900	11.8	260	NA	148.55	NA
C2-PC	76.1	3.2	23.7	900	11.8	260	25.03	264.40	266.73
C3-FRC	76.1	3.2	23.7	900	11.8	260	33.03	284.65	291.10
C4-HS	88.9	4.0	22.3	900	10.1	260	NA	223.20	NA
C5-PC	88.9	4.0	22.3	900	10.1	260	25.03	356.25	387.06
C6-FRC	88.9	4.0	22.3	900	10.1	260	33.03	390.15	414.01
S7-HS	72.0	3.2	22.5	900	12.5	260	NA	170.10	NA
S8-PC	72.0	3.2	22.5	900	12.5	260	25.03	270.80	237.83
S9-FRC	72.0	3.2	22.5	900	12.5	260	33.03	285.35	258.43
S10-HS	91.5	3.6	25.4	900	9.84	260	NA	261.85	NA
S11-PC	91.5	3.6	25.4	900	9.84	260	25.03	518.85	493.27
S12-FRC	91.5	3.6	25.4	900	9.84	260	33.03	550.75	538.60

The concrete mix was obtained using the following dosages: 3.75 kN/m^3 of Portland cement, 5.23 kN/m^3 of sand, 11.62 kN/m^3 of coarse aggregate with maximum size 12 mm, and 0.192 m^3 of water. The fibres employed as 1 % by volume of concrete with steel corrugated type of length L_f = 48 mm and diameter D_f = 0.6 mm (aspect ratio L_f /D_f = 80). The fibres were mixed randomly during the preparation of concrete. In order to characterize the mechanical behaviour of concrete, three cubic, three prismatic and three cylindrical specimens were prepared from each concrete and tested. The mean values of the strength related properties of concrete at an age of 28 days are summarized in Table-2. During preparation of the test specimens, concrete was cast in layers and light tamping of the steel tube using wooden hammer was performed for better compaction. The specimens were cured for 28 days in a humidity-controlled room.

Table 2: Concrete properties

Type of Concrete	**fck (MPa)***	**fcr (MPa)***	**fct (MPa)***
Plain Concrete (PC)	25.03	3.06	2.26
Fibre Reinforced Concrete (FRC)	33.03	3.19	2.86

*average of three cubes, prisms and cylinders respectively

Test Setup and Procedure

All the tests were carried out in an Electronic Universal Testing Machine of a capacity 1000 kN. The columns were hinged at both ends and axial compressive load applied. Test set up of columns as shown in Fig 1. An initial load of about 5 kN was applied to grip the specimen in position. Dial gauges were used to measure the lateral and longitudinal deformations of the columns. The load was applied in the incremental of 20 kN. At every load increment, the deformations were noted. All the specimens were loaded till failure.

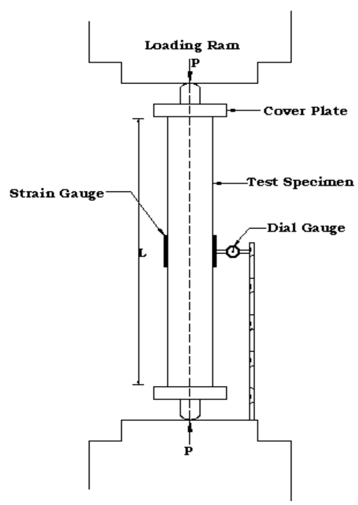

Fig. 1: Test set up of CFST Column

II. TEST RESULTS AND DISCUSSIONS

The usage of fibres in concrete uplift the load carrying capacity to a better extent compared with conventional concrete filled steel tubular columns and decreases the lateral deformations. Fig.2 shows the load carrying capacity of square and circular column of varying cross section. From the fig. 2 it was noted that load carrying capacity of square column of all sizes, hollow as well as in-filled with plain concrete and fibre reinforced concrete is more than that of circular columns. Fig. 3 shows the load – lateral deflection pattern of hollow tubular circular and square columns.

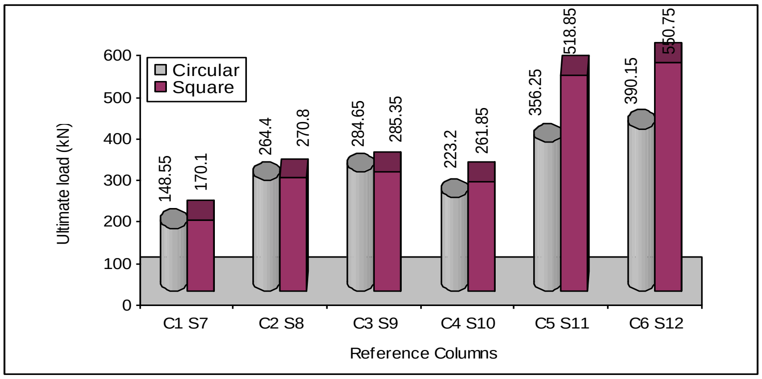

Fig. 2: Comparison of load carrying capacity of all columns in Electronic UTM (1000 kN)

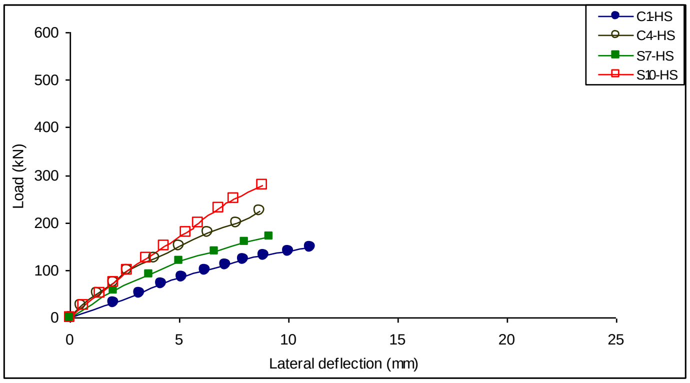

Fig. 3: Load - Lateral deflection for hollow column

From fig. 3 it was observed that hollow square columns perform better than the hollow circular column. When compare to circular column, the strength of the square column is 15-45 % higher. Also, when comparing strength to weight ratio of 72.0 mm hollow square column is about 41 % more than that of 76.1 mm hollow circular column and 91.5 mm hollow square column is about 13 % more than 88.9 mm hollow circular column. Hence about 30 % of steel can be saved when square columns are preferred for the same load capacity. For the same load carrying capacity instead of 76.1 mm dia hollow circular column 60 mm side square column and 88.9 mm dia hollow circular column 75 mm side square column are suggested to increase the working space area.

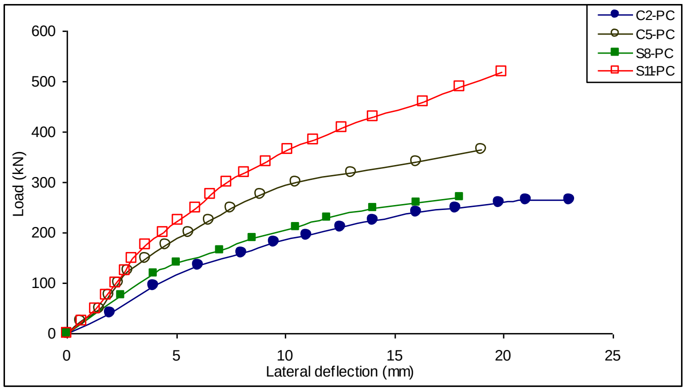

Fig. 4: Load - Lateral deflection for plain concrete column

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Fig. 4 shows the load - lateral deflection pattern of circular and square columns in-filled with plain concrete. From fig. 4 it is also noted that tubular columns in-filled with plain concrete of M_{20} grade is taking more load than hollow column. Comparing fig. 3 and fig. 4, the strength of in-filled column with plain concrete is increased about 58 to 98 %. When comparing square and circular columns in-filled with plain concrete, square column is taking about 3 to 45 % more load than that of circular column.

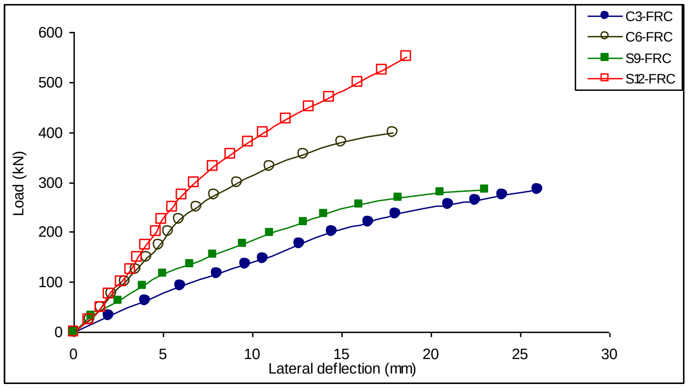

Fig. 5: Load - Lateral deflection for fibre reinforced concrete column

Fig. 5 shows the load - lateral deflection pattern of circular and square columns in-filled with fibre reinforced concrete. From fig. 5 it is noted that tubular column in-filled with fibre reinforced concrete taking 5 - 10 % more load than that of normal concrete. When compare to hollow column, column in-filled with fibre reinforced concrete taking 67 - 110 % more load. When compare to fibre reinforced concrete in-filled circular column taking 3 - 41 % more load than square column. Hence if square columns are adopted, there will be a saving in cost for steel about 30 % when compared with circular columns.

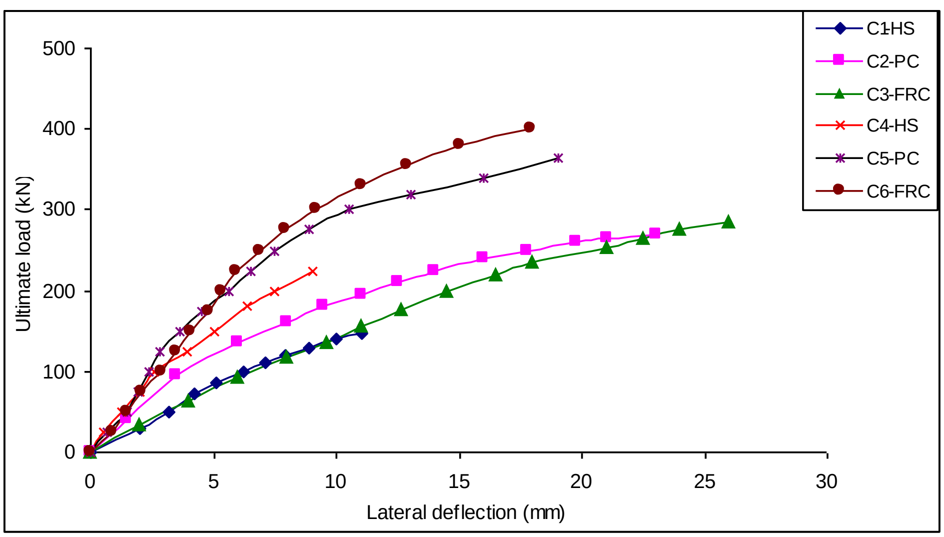

Fig. 6: Load - Lateral deflection for circular column

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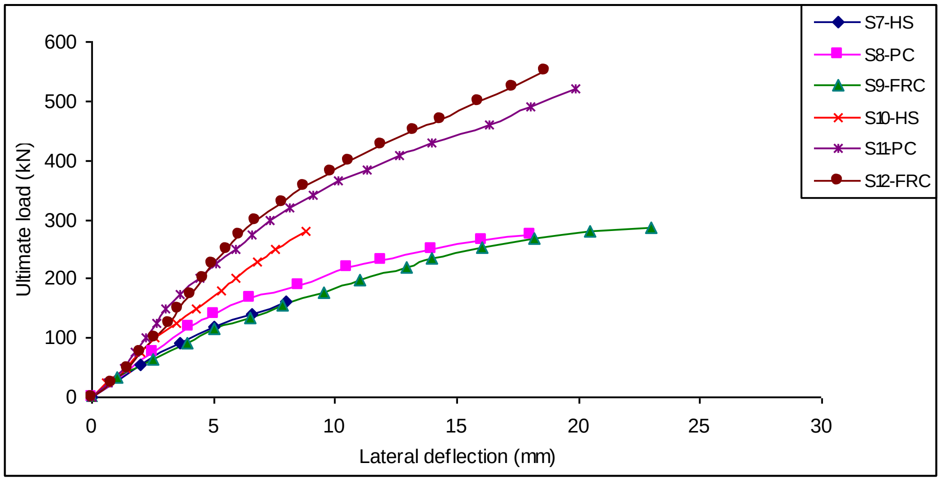

Fig. 7: Load - Lateral deflection for square column

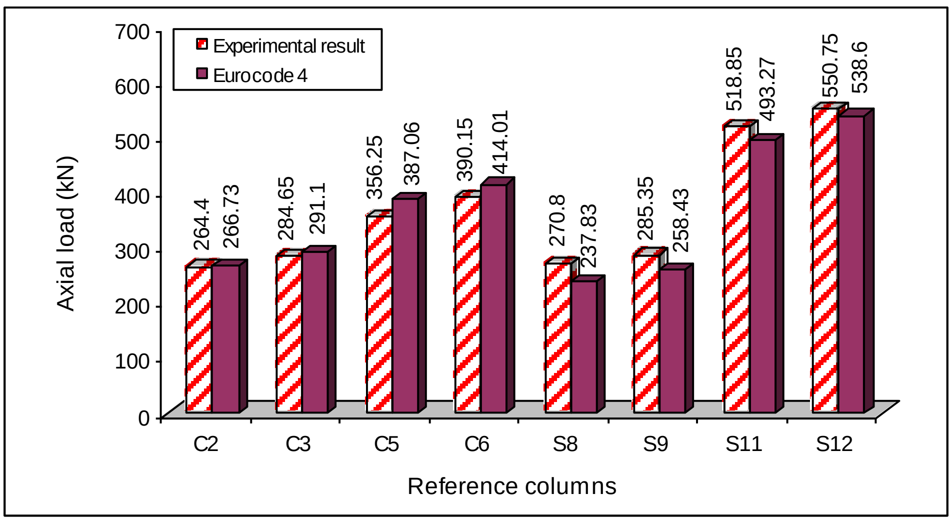

Fig. 8: Comparison of test result with Eurocode 4

Fig. 6 & 7 compares the load - lateral deflection pattern for circular and square columns of hollow section, in-filled with plain concrete and fibre reinforced concrete. From that it is well understood that fibre reinforced concrete in-filled steel tubular sections are performing well. Fig. 8 shows the comparison of experimental result with predicted load by EC4. From the fig. 8, it is found that experimental results are almost same as that of predicted results of Eurocode4.

III. CONCLUSIONS

The results obtained from the tests on composite columns presented in this paper allow the following conclusions to be drawn.

- Square column taking 15 – 45 % more load than circular column. Hence size reduction for square column is possible.

- For square column 30 % cost saving can be achieved when compare to circular column of same cross section.
- Plain concrete in-filled columns are taking 58 – 98 % more load than hollow columns.
- Fibre reinforced concrete filled column is taking 67 – 110 % more load than hollow column and 5 - 10 % more than that plain concrete.
- If fibre reinforced concrete square columns are adopted, there will be a saving in cost for steel about 30 % when compared with circular columns.
- For the same load carrying capacity instead of 76.1 mm dia hollow circular column 40 mm side fibre reinforced concrete in-filled square column and 88.9 mm dia hollow circular column 60 mm side fibre rein forced concrete in-filled square column are suggested to increase the working space area.
- By in-filling fibre reinforced concrete about 50 % steel can be saved when compared to hollow sections.
- Good prediction was achieved for C2, C3, S11 & S12 with measured load to predicted load ratio around unity.
- The predicted axial strengths using Eurocode 4 were maximum of 9 % higher (C5) and 12 % lower (S8) than the results obtained from experiments.

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