MATEC Web of Conferences **400**, 03001 (2024) https://doi.org/10.1051/matecconf/202440003001
SPICE 2024

Utilization of Waste Materials in Concrete Filled Steel Tubular Columns

Mohanraj Erode Krishnasamy[1*], *Ravisankar* Kanjikovil Loganathan[2] and *Selvi* Kaliappan[2]

[1] Professor, Department of Civil Engineering, Nandha Engineering College, India
[2] Assistant Professor, Department of Civil Engineering, Nandha Engineering College, India

Abstract. The idea of this particular study is to utilize waste materials in an effective manner so as to give strength to tubular sections. Steel-Concrete composite construction has emerged as one of the fastest methods of construction in India. The inherent advantage of the steel-concrete composite section lies in that the two principal elements-the steel and the concrete are normally used in a manner so that full potential of both may be realized and the best utilization of their respective properties can be made. In this paper, an attempt was made with steel tubular columns in-filled with plain concrete, partial replacement of fine aggregate by fly ash & quarry dust and coarse aggregate by rubber, slag from steel industry, granite and construction & demolition (C&D) debris concrete. The column specimens are to be tested under axial compression to investigate the effects of waste materials. The effects of steel tube dimensions and the strength of concrete are examined. 24 specimens were tested with strength of concrete as 20 MPa and D/t ratio 23.65. The columns were 113.5 mm outer dimension and 4.8 mm in thickness are 300, 600 & 900 mm in length. The test results are to be compared with the values predicted by Eurocode4, Australian Standards and American Codes and new theoretical models will be suggested for the design. From the test results it was observed that the load carrying capacity of steel tubular columns filled with various waste materials concrete is greater than the conventional concrete.

1 Introduction

Waste materials are a common problem in modern living. Waste minimization is increasingly seen as an ecologically sustainable strategy for alleviating the need to dispose of waste materials, which is often costly, time and space consuming, and can also have significant detrimental impacts on the natural environment. Within India, the government is concerned with developing policies and programmes to bring about successful outcomes to waste minimization. This is seen as being essential to reduce the total amount of waste materials going into landfill, especially in the urban areas where land is very scarce. Recycled materials usually produce cheaper end products for the consumers, hence further justifying their use from an economical viewpoint. Waste materials aggregate concrete can utilize demolition material from concrete and masonry constructions. Though several studies have been made

* Corresponding author:mohanrajcivil8899@gmail.com

on the reuse of concrete waste, only limited studies have been made with respect to use of demolition brick masonry as aggregate. Most of the waste materials produced by demolishing structures are disposed by dumping them as land fill or for reclaiming land. But with the demand for land increasing day by day, the locations, capacity and width of the land that can receive waste materials are becoming limited. Add to it the cost of transportation, which makes disposal a major problem. Hence, reuse of demolition waste appears to be an effective solution and the most appropriate and large-scale use would be to use it as aggregates to produce concrete for new construction.

The technique of composite construction has assumed great importance due to some of its inherent advantages in comparison to the cast-in-situ construction concrete. A major application of this technique in housing is the construction of composite beams, columns and slabs made of cement concrete with rolled steel sections. But in India many constructions are not used these type of steel tubular composite sections due to lack of awareness. Steel members have the advantages of high tensile strength and ductility, while concrete members have the advantages of high compressive strength and stiffness. Composite members combine steel and concrete, resulting in a member that has the beneficial qualities of both materials. The two main types of composite column are the steel-reinforcement concrete column (Fig-1), which consists of a steel section encased in reinforced or un-reinforced concrete, and the concrete-filled steel tubular (CFST) columns (Fig-2), which consists of a steel tube filled with concrete. CFST columns have many advantages over steel-reinforcement concrete columns. The major benefits of concrete filled columns are:

- Steel column acts as permanent and integral formwork
- The steel column provides external reinforcement, and
- The steel column support several levels of construction prior to concrete being pumped.

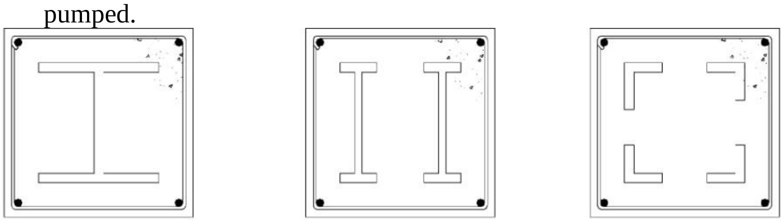

Fig. 1. Concrete Encased Composite Columns

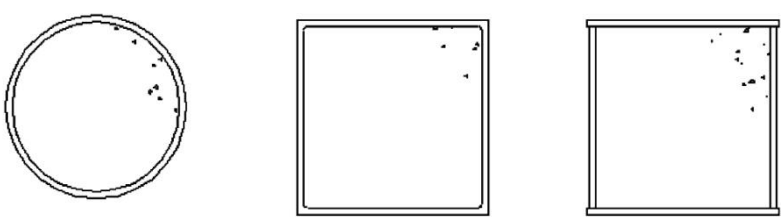

Fig. 2. Concrete Filled Composite Columns

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 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	outer dimension of column
t	wall thickness of steel tube
N_{EC4}	ultimate axial load of composite column
$N_{ACI/AS}$	ultimate squash load
A_s	area of steel tube
A_c	area of concrete
f_{cc}, f_{ck}	characteristics cube compressive strength of concrete
f_{cy}	cylinder compressive strength of concrete (0.8 times of f_{cc})
f_{cr}	modulus of rupture of concrete (flexural tensile strength)
f_{ct}	Splitting tensile strength of concrete
η_1	co-efficient of confinement for concrete
η_2	co-efficient of confinement for steel

1.1 Concrete Filled Steel Tubular Sections

Square and 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 uses of CFSTs provide large saving in cost by increasing the floor area by a reduction in the required cross-section size. This is very important in the design of tall buildings in cities where the cost of letting spaces are extremely high. These are particularly significant in the lower storey of tall buildings where short columns usually exist. CFSTs can provide an excellent monotonic and seismic resistance in two orthogonal directions. Using multiple 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]. 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 vast majority of these experiments have been on moderate scale specimens (less than 200mm in size) using normal and high-strength concrete and there is no much research on study of CFSTs in-filled with concrete using waste materials.

Mandal *et al* [2] reported in his paper elsewhere have shown that the strength of recycled aggregate concrete is comparatively lower than that of similar mix of conventional concrete. However, with the use of fly-ash, it may be possible to produce recycled aggregate concrete with an improvement in strength. The results of this investigation also show that drying shrinkage strain, permeability and water absorption of the recycled aggregate concrete is more compared to conventional concrete. However, the quality of recycled aggregate concrete is found to be improved considerably with the addition of fly-ash. This, in turn, improves the durability of recycled aggregate against sulphate and acid attack. Therefore, the result of that study provide a strong support for the feasibility of using recycled aggregates instead of natural aggregates for the production of concrete. He suggested that more research studies on recycled aggregate concrete are necessary for the practical application of recycled aggregate concrete.

Ramamurthy and Gumaste [3] studied the properties of a recycled aggregate concrete and he reported that recycled aggregates possess relatively lower bulk density and higher water absorption as compared to those of fresh granite aggregates. The compressive strength of recycled aggregate concrete is relatively lower and the variation depends on the strength of original (demolished) concrete from which the aggregates have been obtained.

This reduction is mainly caused by the bond characteristics of recycled aggregate and the fresh mortar of the recycled concrete.

Sahu *et al* [4] concluded in his paper that if 40 percent sand is replaced by quarry dust in concrete, it will not only reduce the cost of concrete but at the same time will save large quantity of natural sand and will also reduce the pollution created due to the disposal of this stone dust on valuable fertile land. There has been inadequate utilization of large quantities of crushed stone as alternative material left out after crushing of rock to obtain coarse aggregate / ballast for concrete. Crushed stone dust does not satisfy the standard specification of fine aggregate in cement mortar and concrete. Efforts have been made to replace river sand by rock dust. Nagaraj *et al* [5] has studied the effect of rock dust and pebble as aggregate in cement and concrete. They found that crushed stone dust could be used to replace the natural sand in concrete. Shukla *et al* [6] investigated the behaviour of concrete made by partial / full replacement of river sand by crushed sand dust as fine aggregate and reported that 40 percent can be replaced by crushed stone dust without affecting the strength of concrete.

A series of tests had been carried out by O'Shea and Bridge [7] on the behaviour of circular thin-walled steel tubes. The tubes had diameter to thickness D/t ranging between 55 and 200. The tests included; 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 test strengths were compared to strength models in design standards and specification. 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 [8] 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 if only the concrete is loaded and the steel is not bonded to the concrete. For steel tubes with a D/t ratio greater than 55 and filled with 110-120 MPa high-strength concrete, the steel tubes provide insignificant confinement to the concrete when both the steel and concrete are loaded simultaneously. 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 [8]. Two possible failure modes of the steel tube had been identified, 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 design method has been suggested based upon the recommendations in EC4 [9].

Kilpatrick et al [10,11] 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 EC4. The concrete strength of columns ranged from 23 to 103 MPa. The mean ratio of measured / predicted column strength was 1.10 with a standard deviation of 0.13. The EC4 safely predicted the failure load in 73% of the column analyzed. For axially loaded thin-walled steel tubes, local buckling of the steel tube 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 EC4 with no reduction for local buckling.

V. Gayathri et al [26] study the cross-sectional behavior of concrete-filled steel tubes subjected to monotonic and cyclic loading under fiber-based approach. Constitutive behavior of the cross-section is formulated by explicitly dividing the section into fibers, and uniaxial stress-strain rules for steel and concrete are defined. Interaction curves, Moment-Thrust-Curvature (M-P-φ) relations and Moment-Thrust-Strain (M-P-ε) relations are developed for circular and box-shaped in-filled sections based on fiber analysis. A fiber model is also developed to describe the nonlinear response of concrete-filled steel tubes subjected to cyclic loading. M-P-φ relations are developed for arbitrary loading histories using this simple yet reliable approach. Results are compared with the numerical and experimental data available in published literature, and the accuracy of the proposed model is thus ascertained.

Fei-Yu Liao et al [29] reports test results of 10 CFSST columns under constant axial load and cyclically increasing flexural loading. Concrete-filled stainless steel tubular (CFSST) columns have attracted increasing research interests in recent years; however, it seems that the behavior of this type of innovative column under cyclic loading has not been addressed sufficiently so far. The main parameters varied in the experiments were axial load level, cross-sectional type, and concrete type. The influences of these parameters on strength, ductility, stiffness, and energy dissipation were investigated. It was found that CFSST columns exhibited excellent energy dissipation and ductility, even when the specimens were subjected to high axial loads. The hysteretic behavior of the tested CFSST columns was compared to that of their carbon steel composite counterparts reported in the literature. Several existing design codes were used to predict the ultimate strength and flexural stiffness of the test specimens, and some suggestions are proposed accordingly for designing CFSST columns.

2 Experiments

A total of twenty-four specimens of Square (designated S) sections were tested for this study. All specimens were tested with strength of concrete as 20 MPa and a D/t ratio 23.65. The columns were 113.5mm in side and 300, 600 & 900 mm in length.The column specimens were classified into eight different groups filled with plain concrete (designated P), partial replacement of fine aggregate by 10% fly-ash (designated FA) and 40% quarry dust (designated QD) and coarse aggregates by 25% rubber (designated R), 25% steel slag (designated S), 25% granite (designated G) and 25% C & D debris (designated CD). The rest of the column specimens were tested as hollow sections for comparison (designated H).

All the specimen properties are given in Table 1. All the specimens were fabricated from square hollow steel tube and filled with seven types of concrete. The average values of yield strength and ultimate tensile strength for the steel tube were found to be 260 and 320 MPa respectively. In the present experimental work, the parameters of the test specimens are the size of specimen, strength of concrete and L/D ratio of columns. In order to prevent the steel hollow column section from local buckling, ACI [12] required the width-to-thickness (B/t) ratio of the steel hollow section not greater than the following limit:

for 113.5 mm side the B/t is 23.65 $<\sqrt{(3E_s/f_y)} = 48.63$

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. Fly-ash (waste from thermal plant - *Mettur Thermal Plant*), quarry dust (waste from crusher), slag (waste from steel industries) granite (waste pieces from granite industries) and C&D debris (construction and demolition debris) by weight basis and rubber (waste pieces from tire) by volume basis are taken. In order to characterize the

Table 1. Specimen properties

Reference Columns	Side D (mm)	Thickness t (mm)	D/t	Length L (mm)	L/D	Steel Strength f_y (MPa)	Concrete Cube

							Strength f_{cu} (MPa)
S1-HC	113.5	4.8	23.65	300	2.64	260	NA
S2-PC	113.5	4.8	23.65	300	2.64	260	25.03
S3-FA	113.5	4.8	23.65	300	2.64	260	22.75
S4-QD	113.5	4.8	23.65	300	2.64	260	24.47
S5-GR	113.5	4.8	23.65	300	2.64	260	23.26
S6-CD	113.5	4.8	23.65	300	2.64	260	28.14
S7-RC	113.5	4.8	23.65	300	2.64	260	20.15
S8-SS	113.5	4.8	23.65	300	2.64	260	21.48
S9-HC	113.5	4.8	23.65	600	5.29	260	NA
S10-PC	113.5	4.8	23.65	600	5.29	260	25.03
S11-FA	113.5	4.8	23.65	600	5.29	260	22.75
S12-QD	113.5	4.8	23.65	600	5.29	260	24.47
S13-GR	113.5	4.8	23.65	600	5.29	260	23.26
S14-CD	113.5	4.8	23.65	600	5.29	260	28.14
S15-RC	113.5	4.8	23.65	600	5.29	260	20.15
S16-SS	113.5	4.8	23.65	600	5.29	260	21.48
S17-HC	113.5	4.8	23.65	900	7.93	260	NA
S18-PC	113.5	4.8	23.65	900	7.93	260	25.03
S19-FA	113.5	4.8	23.65	900	7.93	260	22.75
S20-QD	113.5	4.8	23.65	900	7.93	260	24.47
S21-GR	113.5	4.8	23.65	900	7.93	260	23.26
S22- CD	113.5	4.8	23.65	900	7.93	260	28.14
S23-RC	113.5	4.8	23.65	900	7.93	260	20.15
S24-SS	113.5	4.8	23.65	900	7.93	260	21.48

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.

Table 2. Concrete properties

Type of Concrete	**f_{ck} (MPa)***	**f_{cr} (MPa)***	**f_{ct} (MPa)***
Conventional concrete	25.03	3.06	2.26
Partial replacement of fine aggregate by fly-ash 10 %	22.75	3.19	2.44
Partial replacement of fine aggregate by quarry dust 40 %	24.47	3.17	2.53
Partial replacement of coarse aggregate by granite 25 %	23.76	3.07	2.35
Partial replacement of coarse aggregate by C&D debris 25%	28.14	3.50	2.82
Partial replacement of coarse aggregate by rubber 25%	20.15	2.81	1.31
Partial replacement of coarse aggregate by steel slag 25%	21.48	3.37	2.31

* average of three cubes, prisms and cylinders respectively

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 as shown in Fig 3. A pre-load of about 5 kN was applied to hold the specimen upright. Dial gauges were used to measure the lateral and longitudinal deformations of the columns. The load was applied in small increments of 20 kN. At each load increment, the deflection at centre was recorded. All specimens were loaded up to failure.

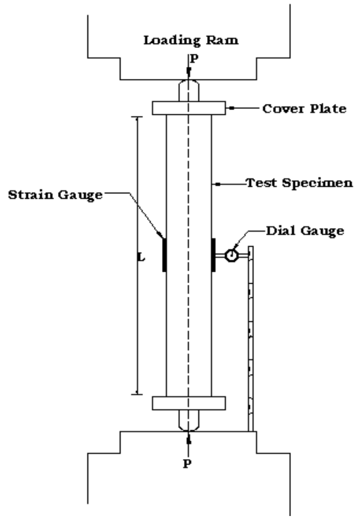

Fig. 3. Test set up of Concrete Filled Steel Tubular Column

3 Comparison with Eurocode 4 (EC4), ACI 318-95 (ACI) and Australian Standards AS 3600 & AS 4100 (AS)

EC4 [9] is the most recently completed international standard in composite construction. EC4 covers concrete-encased and partially encased steel sections and concrete-filled sections with or without reinforcement. EC4 uses limit state concepts to achieve the aims of serviceability and safety by applying partial safety factor to load and material properties. EC4 is the only code that treats the effects of long-term loading separately.
The ultimate axial force of a column is

$$N_{EC4} = A_s f_y \eta_2 + A_c f_{cc} (1+ \eta_1 (t f_y / D f_{cy})) \quad (1)$$

The ACI [12] and Australian Standards [13] use the same formula for calculating the squash load. Neither code takes into consideration the concrete confinement. The limiting thickness of steel tube to prevent local buckling is based on achieving yield stress in a hollow steel tube under monotonic axial loading which is not a necessary requirement for an in-filled composite column.

The squash load is determined by

$$N_{ACI/AS} = 0.85 A_c f_{cc} + A_s f_y \quad (2)$$

Detailed comparisons of load carrying capacity of composite columns are presented in Table 3. For the first set of specimens having small L/D ratio (2.64) is the increase in value of N_{test} ranges from 3 to 15 %. Where as in the case of second set of specimens with L/D ratio of 5.29 the N_{test} values increases ranges from 9 to 18 % and the third set of specimens with large L/D ratio (7.93) the N_{test} values increases ranges from 1 to 10 %. Hence the strength of infill concrete and L/D ratio influences the critical load carrying capacity.

The N_{EC4}, and N_{test} loads of various infill concrete materials is presented in Fig 4. It is observed that the EC4 equation gives an over estimates the load carrying capacity of concrete filled composite columns varying from 0 to 20 % as compared to experimental results. But a comparison with ACI/AS codal equation shows that the equation under estimates the critical load carrying capacity of columns varying upto 11 to 37%. This observation was also made by Georgios Giakoumelis and Dennis Lam [14] hence they proposed a modified equation as $N_{ACI/AS} = 1.3\ A_c\ f_{cc} + A_s\ f_y$. Fig 5 shows the comparison of test results with ACI/ASand the modified ACI/AS equation.

Table 3. Comparison of load carrying capacity with existing code

Ref. Columns	N_{test} (kN)	N_{EC4} (kN)	$N_{ACI/AS}$ (kN)	N_{test}/N_{EC4}	$N_{test}/N_{ACI/AS}$	Modified $N_{ACI/AS}$ (kN)	N_{test}/Modified $N_{ACI/AS}$
S1-HC	466.55	394.32	500.88	NA	NA	NA	NA
S2-PC	895.45	995.26	684.63	0.900	1.308	823.64	1.087
S3-FA	820.45	976.82	667.89	0.840	1.228	798.03	1.028
S4-QD	906.45	990.73	680.52	0.915	1.332	817.34	1.109
S5-GR	923.55	980.94	671.64	0.941	1.375	803.76	1.149
S6-CD	925.65	980.44	707.46	0.944	1.308	858.54	1.078
S7-RC	800.65	955.81	648.81	0.838	1.234	768.84	1.041
S8-SS	835.55	990.50	693.35	0.844	1.205	783.77	1.066
S9-HC	455.55	412.97	500.88	NA	NA	NA	NA
S10-PC	820.50	886.97	684.63	0.925	1.198	823.64	0.996
S11-FA	805.65	869.27	667.89	0.927	1.206	798.03	1.009
S12-QD	850.45	882.62	680.52	0.964	1.250	817.34	1.041
S13-GR	869.45	873.23	671.64	0.996	1.295	803.76	1.082
S14-CD	860.05	911.15	707.46	0.944	1.215	858.54	1.002
S15-RC	738.95	849.12	648.81	0.870	1.139	768.84	0.961
S16-SS	805.55	899.30	693.35	0.896	1.162	783.77	1.028
S17-HC	420.30	431.62	500.88	NA	NA	NA	NA
S18-PC	790.85	803.86	684.63	0.984	1.155	823.64	0.960
S19-FA	775.85	786.38	667.89	0.987	1.162	798.03	0.972
S20-QD	820.55	799.56	680.52	1.026	1.205	817.34	1.004
S21-GR	829.55	790.28	671.64	1.050	1.235	803.76	1.032
S22-CD	846.65	827.78	707.46	1.023	1.196	858.54	0.986
S23-RC	778.50	766.50	648.81	1.016	1.200	768.84	1.013
S24-SS	770.55	795.55	693.35	0.968	1.111	783.77	0.983

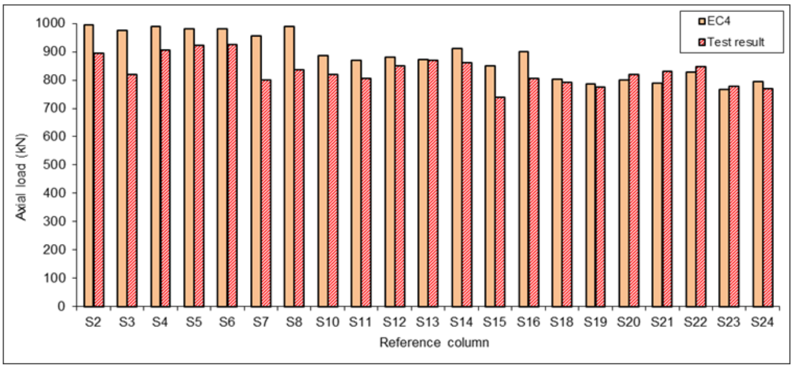

Fig. 4. Comparison of test result with EC4

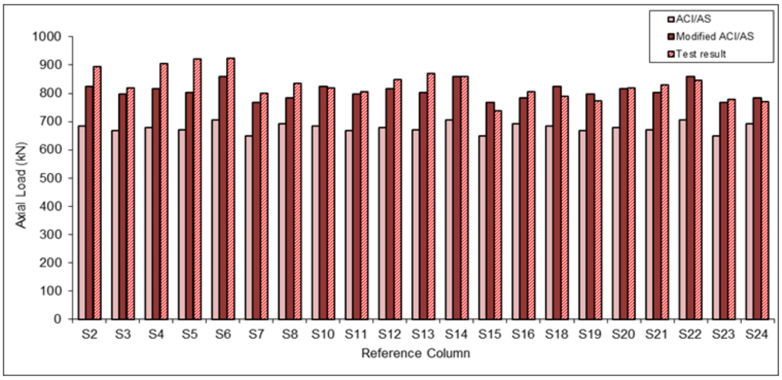

Fig. 5. Comparison of test result with ACI/AS and modified ACI/AS

4 Test Results and Discussions

The tests were conducted on 24 specimens with different L/D ratio of 2.64 ≈ 3.0, 5.29 ≈ 6.0 & 7.93 ≈ 8.0 and also with infilling of plain concrete and partial replacement of fine aggregate by fly-ash & quarry dust and coarse aggregate by granite, rubber, slag and C&D debris. The test results were given in fig. 4 & 5.

Fig. 4 & 5 compares the relationship between compressive strength of concrete to strength of column predicted by EC4, ACI/AS, modified ACI/AS [14] and experimental test results. From the Fig. 4 and Table 3 it was observed that ACI/AS under estimate the strength of column but modified ACI/AS is correlating with experimental results (L/D=8) and hence

$$N_{ACI/AS} = 1.3\ A_c\ f_{cc} + A_s\ f_y \qquad (3)$$

Above equation is applicable for steel tubular section in-filled with concrete.

Also, it was noticed that when L/D ratio reduces, the predicted strength also reduces. In EC4 code, the difference between predicted and actual strength is 15 - 66 % only because the slenderness effect has been considered. But in ACI/AS, the difference is upto 74 % because there is no consideration for slenderness effect or L/D ratio. Hence this equation may be hold good for L/D > 8 some factor should be multiplied with the existing ACI/AS equation to predict the exact strength.

In this study, from experimental results, a factor **k** is suggested for different L/D ratio and the values of **k** are tabulated below in Table 4. Now the equation is slightly modified by multiplying a factor **'k'.**

The proposed equation for column is

$$N_{ACI/AS} = \mathbf{k}\ [0.85\ A_c\ f_{cc} + A_s\ f_y] \qquad (4)$$

To validate the proposed equation three columns of different dimensions have been tested and compared with predicted results and the results are tabulated in Table 5. From Table 5 it was found that proposed equation gives almost same strength obtained by experimental result.

Table 4. Values of k for different L/D ratio

L/D ratio	1	2	3	4	5	6	7	8	9	10	11	12
k factor	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.0	0.9	0.8

Table 5. Comparison of test results with proposed equation

Outer Dimension	Thick	L/D	Test result	ACI/AS	Proposed eqn.
114.3 mm	4.5 mm	5.25	810.00 kN	551.80 kN	816.66 kN
114.3 mm	4.5 mm	7.15	788.80 kN	481.95 kN	747.05 kN
76.10 mm	3.2 mm	3.94	417.30 kN	255.48 kN	408.77 kN
72.00 mm	2.0 mm	12.5	220.60 kN	167.37 kN	217.58 kN
88.90 mm	4.0 mm	10.1	385.95 kN	356.90 kN	393.67 kN

5 Conclusions

The results obtained from the tests on composite columns presented in this paper allow the following conclusions to be drawn. The predicted axial strengths using EC4 are lower than the results obtained from experiments ranging from 0 to 20 %. The ACI/AS also under estimates the strengths and the variation is 11 to 37 %. ACI/AS equation gives better results for long columns of L/D > 8. For L/D < 12, modified equation is proposed with the multiplying factor '**k**', **k** values are suggested for different L/D ratio varying from 1 to 12. The verification experiment indicates that the proposed equation more accurately predicts the strength of concrete filled tubular columns.

The strength of steel tubular columns in-filled with concrete is about 18 to 120 % of hollow columns, and the strength depends on the compressive strength of the in-filled materials. The strength of CFSTs with partial replacement of fine and coarse aggregate by waste materials is almost same as that of plain concrete. The strength of partial replacement of quarry dust as fine aggregate and granite, C&D debris and slag as coarse aggregate in CFST columns is more than that of plain concrete. Excellent prediction was achieved for S15, S16, S18, S19 & S24 CFST columns, with $N_{test}/N_{ACI/AS}$ ratio around unity. Excellent prediction was achieved for S2, S3, S6-S8, S10-S16 & S18-S24 CFST columns, with N_{test}/modified $N_{ACI/AS}$ ratio around unity.

References

[1] Hajjar, J. F. "Composite steel and concrete structural systems for seismic engineering" J. Constructional Steel Research, 59 (58), pp. 03-723 (2002)
[2] Mandal S, "Some studies on durability of recycled aggregate concrete" The Indian Concrete Journal, pp 385-388 (2002)
[3] Ramamurthy K and Gumaste K.S. "Properties of recycled aggregate concrete" The Indian concrete Journal, pp 49-53 (1998)
[4] Sahu A.K., Sunil Kumar and Sachan A.K, "Crushed stone waste as fine aggregate for concrete" The Indian Concrete Journal, pp 845-848 (2003)
[5] Nagaraj T.S. and Zahida Banu, "Efficient utilization of rock dust and pebbles as aggregates in Portland cement concrete" The Indian Concrete Journal, Vol 70, No: 1, pp 1-4 (1996)
[6] Shukla M, Sahu A.K. and Sachan A.K., "Performance of stone dust as fine aggregate replacing sand in concrete and mortar" National seminar on Advances in Special Concretes, Indian Concrete Institute, Bangalore, pp 241-248 (1998)
[7] O' Shea, M. and Bridge, R., "Circular thin-walled tubes with high strength concrete infill" Composite construction in steel and concrete II, Germany, ASCE, pp. 780-793 (1996)
[8] O'Shea, M. and Bridge, R, "The design for local buckling of concrete filled steel tubes" Composite Construction-Conventional and Innovate, Austria, pp.319-324 (1997)
[9] Eurocode 4. DD ENV 1994-1-1, Design of Composite Steel and Concrete Structures. Part 1.1, General Rules and Rules for Buildings (with UK National Application Document). London, British Standards Institution (1994)

[10] Kilpatrick, A. and Rangan, B. V., “Behaviour of high-strength composite column” In: Composite Construction – Conventional and Innovate, Innsbruck, Austria, pp. 789-794 (1997)
[11] Kilpatrick, A. and Taylor, T. “Application of Eurocode 4 design provisions to high strength composite columns” In: Composite Construction – Conventional and Innovate, Innsbruck, Austria, pp. 561-566 (1997)
[12] ACI Committee 318. “Building Code requirements for Structural Concrete (ACI 318-95)” Detroit: American Concrete Institute. (1995)
[13] Australian Standards AS3600 & AS4100. “Reinforced Concrete Structures & Steel Structures” Sydney: Standards Australia. (1994)
[14] Georgios Giakoumelis and Dennis Lam, “Axial capacity of circular concrete-filled tube columns” Journal of Constructional Steel Research, Proc. 60, pp.1049-1068.
[15] Brauns, J., “Analysis of stress state in concrete-filled steel column” J. Constructional Steel Research, 49(2), pp. 189-196. (1998)
[16] O’ Shea, M. and Bridge, R., “Design of circular thin-walled concrete filled steel tubes” Journal of Structural Engineering, ASCE, Proc. 126, pp. 1295 – 1303 (2000)
[17] Shanmugam, N. E. and Lakshmi, B, “State of the art report on steel-concrete composite columns” Journal of Constructional Steel Research, Proc. 57, pp. 1041-1080 (2001)
[18] Johansson, M. and Gylltoft, K., “Structural behaviour of slender circular steel-concrete composite columns under various means of load application” Journal of Constructional Steel Research, Proc. 01, pp.393-410 (2001)
[19] Gopal, S. R. and Manoharan, P. D, “Experimental behaviour of eccentrically loaded slender circular hollow steel columns in-filled with fibre reinforced concrete” Journal of Constructional Steel Research, pp. 513-520 (2006)
[20] Johnson, R. P, “Composite Structures of Steel and Concrete. Blackwell Scientific Publications (2nd edition), (2004)
[21] Wang, Y. and Wu, H. C., “Concrete Reinforcement with Recycled Rubbers” Journal of Materials in Civil Engineering, ASCE, 12 (4), pp. 314-319 (2006)
[22] Amjad Masood. “Variation in Strength of Concrete on Addition of Demolished Waste” Indian Concrete Journal, pp. 395-399 (1998)
[23] Mohanraj E. K, Ravisankar K.L, Karthika P, Manikandan P, Enhancement of load carrying capacity of steel tubular columns in-filled with fibre reinforced concrete, International journal of psychosocial rehabilitation, 23(4) 1711 (2019)
[24] Mohanraj E.K., Kandasamy S., Malathy R., “Behaviour of steel tubular stub and slender columns filled with concrete using recycled aggregates”, Journal of the South African Institution of Civil Engineering, v. 53, n. 2, pp. 31-38 (2011)
[25] N. Chandrasekaran, Dr. E.K. Mohanraj, Experimental Evaluation of New Concrete Encased Concrete Beam to Column Joint by using Composite Material, International Journal of Advanced Engineering Technology, Vol: VII, Issue III, pp.71-75 (2016)
[26] V.Gayathri, N.E.Shanmugam and Y.S.Choo, Concrete-Filled Tubular Columns:Part1-Cross-Section Analysis, International Journal of Structural Stability and Dynamics, 04, 459 (2004)
[27] Xueping Li and Xilin Lu, Modeling and Seismic Behavior of Concrete-filled Rectangular Steel Tubular Columns in Tall Buildings, Tall Buildings, 187-193 (2005)
[28] Qinghua Tan, Leroy Gardner and Lin Hai Han, Performance of Steel-Reinforced Concrete-Filled Stainless Steel Tubular Columns at Elevated Temperature, International Journal of Structural Stability and Dynamics, 19, 2019.
[29] Fei-Yu Liao; Lin-Hai Han, Zhong Tao and Kim J. R. Rasmussen, Experimental Behavior of Concrete-Filled Stainless Steel Tubular Columns under Cyclic Lateral Loading, Journal of Structural Engineering, 143 (2017)

[30] Lin-Hai Han, Flexural Behaviour of Concrete-Filled Steel Tubes, Journal of Constructional Steel Research, 60 (2), 313-337 (2004)

[31] Yansheng Du, Zhihua Chen, Changqing Zhang & Xiaochun Cao, Research on Axial Bearing Capacity of Rectangular Concrete-Filled Steel Tubular Columns based on Artificial Neural Networks, Frontiers of Computer Science, 11, 863-873 (2017)

[32] Vivian W. Y. Tam, Zhi-Bin Wang & Zhong Tao, Behaviour of recycled aggregate concrete filled stainless steel stub columns, Materials and Structures, 47, 293-310 (2014)

[33] M.H.Lai &J.C.M.Ho, A theoretical axial stress-strain model for circular concrete-filled-steel-tube columns, Engineering Structures, 125, pp124-143 (2016)

[34] N. Chandrasekaran and Dr. E.K. Mohanraj, Experimental and Numerical Analysis of Conventional and GFRP Concrete for Frame Members, International Journal of Solid State Technology, 63 (6), 19953-19970 (2020)

[35] E. K. Mohanraj, R.Malathy and K. L. Ravisankar, Utilization of industrial waste materials in concrete-filled steel tubular columns, Revista material, 27(2). https://doi.org/10.1590/S1517-707620220002.1388 (2022)