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Composite Behavior of Circular Concrete Filled Steel Tubular Column

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ABSTRACT—

Concrete Filled steel Tubes (CFT) are habitually preferred for the construction of high-rise buildings because of high strength, stiffness, reduced cross sectional area, improved fire resistance, more stiffness and other seismic resistance properties like ductility and energy absorption capacity etc., Apart from strength and ductility, adequate bond between steel and concrete at the interface is important in CFT columns to ensure a composite action. One way of improving the bond strength of a CFT column is introducing internal stiffeners (tie bars). This thesis presents a non - linear finite element analysis on circular CFT column with and without tie bars. A finite element model is developed using the general purpose finite element software ANSYS and is used to carry out entire non- linear analysis of hollow, CFT and CFT with Tie bars columns under axial compression of specimens 60 mm diameter and 1.2 mm thickness of steel tube with tie bars of 3 mm diameter. The behavior of CFT columns with slenderness ratios 8, 10, 12 (stub columns) and 14, 16, 18 (slender columns) is to be studied. The numerical analysis values are then compared with theoretical Eurocode 4 values.

Keywords— CFT, Concrete Filled Steel Tubes, Ansys.

I. INTRODUCTION

Concrete-Filled-steel-Tube (CFT) columns are becoming increasingly popular for column constructions of tall buildings due to the composite action between steel and concrete. A number of additional economical benefits stem from the use of CFT. The tube serves as formwork in construction, which decreases labour and material costs. In moderate to high rise construction, the building can ascend more quickly than a comparable reinforced concrete structure since the steelwork can precede the concrete by several stories.

There exist applications in Japan and Europe where CFT are also used as bridge piers [1]. CFT may be utilized for retrofitting purposes for intensification concrete columns in earthquake zones. The CFT structural member has a number of distinct advantages over an equivalent steel, reinforced concrete, or steel-reinforced concrete member. Therefore, it is most advantageous to use CFT for the columns subjected to the high axial loading. Numerous tests have illustrated the increase in cyclic strength, ductility, and damping by filling hollow tubes with concrete.

However, there is a major shortcoming of adopting CFT columns, which is the imperfect interface bonding between concrete and steel tube during initial elastic stage because steel dilates more than concrete [2] . This imperfect bonding will reduce the confining pressure provided by the steel tube and thus reduce the initial stiffness and elastic strength of columns.

This work proposes a new stiffening scheme as an alternative for enhancing the behavior of circular CFT columns in terms of composite action. The proposed stiffening scheme involves welding a set of steel bars called tie bars along the tube axis. This project helps us to study the composite action of circular CFT column with and without tie bars with various slenderness ratios. With the help of this analysis we can say that there is a better performance in composite action using tie bars.

II. REVIEW OF LITERATURES

Uni-axial compressive test of concrete-filled-steel-tube- columns confined by tie bars[2] (2013) (M.H.Lai, J.C.M.Ho) (China). From this investigation they resolve the problem with the enhancement of composite action between steel tube and concrete in CFT columns tie bars were proposed with various column dimensions, concrete strength are tested under uni-axial compression. Totally twenty four CFT columns specimens were fabricated with the outer diameter of 168.3 mm , height of 330 mm, thickness of the steel tube were 5 and 8 mm respectively. The tie bars was installed perpendicularly to the steel tube by bolted connections, spacing of the tie bars are 5t, 10t, 12.5t, 15t and 20t. From the experimental result they conclude that tie bars could increase the load carrying capacity (minimum 16% - average 5%) but tie bars were not effective in improving elastic stiffness of the CFT column.

Design formula of concrete filled circular steel tubes reinforced by carbon fiber reinforced plastic sheets[3] (2011) (J.W.Park, Y.K.Hong) Korea. In this investigation they deals with the problem of local buckling at steel tube due to deterioration of confinement effect after steel tube yield in CFT columns, column system reinforced by CFRP (carbon fiber sheet) and structural behaviors of CFRP and current CFT columns also compared with design formula. They carried out axial compressive test on 10 specimens with various D/t ratio and CFRP sheet layering,. From this investigation they finally concluded that CFRP confined CFT columns will significantly increase the axial load carrying capacity, ductile capacity was decreased due to sudden deterioration in load capacity.

Influence of concrete strength & Length/ Diameter on the axial capacity of CFT Columns[4] (2009) (Watter Luiz Andeade de Oliveria) Brazil. They investigate about the experimental analysis of the confinement effects in circular CFT columns regarding two parameters; compression strength of concrete and column slenderness. The experimental values were compared with EC (4), AINSI/AISC 360:2005 and CAN/CSA S16-01:2001. Totally

16 CFT circular column specimens with various concrete compressive strength (30, 60, 80 and 100 Mpa) and column slenderness (3, 5, 7 and 10), diameter of the column and thickness of the steel tube were 114.3 mm and 3.35 mm. Compressive strength of the column specimens were determined by (10 x 20 cm) cylindrical specimens at 28 days. They conclude that column slenderness showed higher increases in load carrying capacity, EC (4) presented the values closer to the experimental results, load carrying capacity increased with increasing concrete compressive strength and decreased with increasing L/D ratio of the column.

Bond stress characteristics on circular concrete filled steel tubular columns using mineral admixture Metakoline[5] (2012) (Baskar.K) NIT-Trichy. They studied about the bond stress characteristics in Circular CFT column using mineral admixture (metakoline), also the effect of change in length and diameter of the tube, percentage variation of mineral admixture mineral admixture were tested. Diameter of the column and thickness of the steel tube were 150 mm and 5 mm respectively. Yield strength of the steel tube was 310 Mpa, stiffeners bars of 50 mm width and 6 mm thickness were welded with the steel tube. Partial replacement of cement in concrete by mineral admixture metakoline (5, 10, 15 and 20 %). In this push out test the displacement of concrete was allowed up to 35 mm where the ultimate load was observed. Also bond stress were determined at failure load [P/(πDL)]. From this study they conclude that bond carrying capacity increase in percentage of metakoline but increase up to 15%, bond strength of metakoline CFT specimens is greater than CFT specimens, stiffeners were also influenced bond strength.

Bond strength in concrete filled built-up steel tube columns with tab stiffeners[6] (2011) (Clotilda pertrus) Malaysia. They investigated about bond strength of CFT column by providing a internal tab stiffeners by conducting push out test. In this study 25 mm height with 4 mm thickness stiffeners were used. Twenty one square specimens with side length of 200 mm fabricated, from 2 mm thickness steel tubes. Tab spacing derived along the stiffeners various from 75, 100, 150, 300 mm. Compressive strength of the stiffener are 36, 40, 50 Mpa. Tab was welded on long stiffener. To carried out push out test the provision of 50 mm air gap allowed in the bottom of the column. They concluded that failure by crushing of concrete followed by buckling of steel tube and finally bending of tab, degree of improvement increased with decreasing tab, tab spacing 100 mm are closer 50% higher than control column, 100 mm tab spacing with 50 Mpa compressive strength of concrete improved by about 40% over those 40 and 36 Mpa compressive strength of concrete.

Non-Linear analysis of axially loaded concrete filled tube columns with confinement effect[7] (2003) (Hsuan-TCH hu, M.ASCE) China. In this investigation circular, square and square section stiffened by reinforcing ties were proposed and verified by the non-linear FEA program ABAQUS against experimental data. Here reinforced steel used as a stiffener and Concrete poisson's ratio varied from 0.15 - 0.22. The parameters for the circular section (140, 200, 280, and 300 mm), square section (127, 200, 280, and 300 mm), and square stiffener section (200, 280, and 300 mm). They concluded that in CFT circular sections, the tubes provide good confining effect to concrete when (D/t < 40) –local buckling not occur, CFT square section not provide large confining effect to concrete when (B/t > 30) and the local buckling is very likely to take place, CFT square stiffener section is enhanced by using reinforced ties when tie spacing is small and the tie number (or tie diameter) is large and the local buckling was prevented by ties.

Mechanical behavior of circular steel-concrete composite stub columns[8] (2002) (Mathias johansson) Sweden. In this experimental and analytical study on circular CFT stub columns to examine the mechanical behaviour on three conditions. Finite element analysis models were established and verified with experimental results. In this study, 13 circular stub columns were fabricated with diameter 159 mm, height 4.8 mm and length 650 mm. The Loads applied to only on concrete core, only on steel core, both steel and concrete core simultaneously (the provision of 100 mm air gap made at the bottom of the column to carry out push out test). The compressive strength of the concrete and the yield strength of the steel tube were 79.4 and 433 Mpa respectively. Result from finite element analysis shows that the mechanical behavior of column was greatly influenced by the method used to apply the load, bond strength of the column has no influence on behavior.

III. EXPERIMENTAL INVESTIGATION

A total of eighteen test specimens with both stub and slender column members with commercially available steel hollow section under concentric axial compression. The common outer diameter and thickness of the steel tubes are 60 mm and 1.2 mm. The D/t ratio of circular CFT column tested was 50 and slenderness ratio of 8, 10, 12 (short columns) 14, 16 and 18 (long columns) respectively. The rest of the specimens were installed (welded) with tie bars of 3 mm diameter with an equal spacing of 150 mm from the mid section of the specimen.

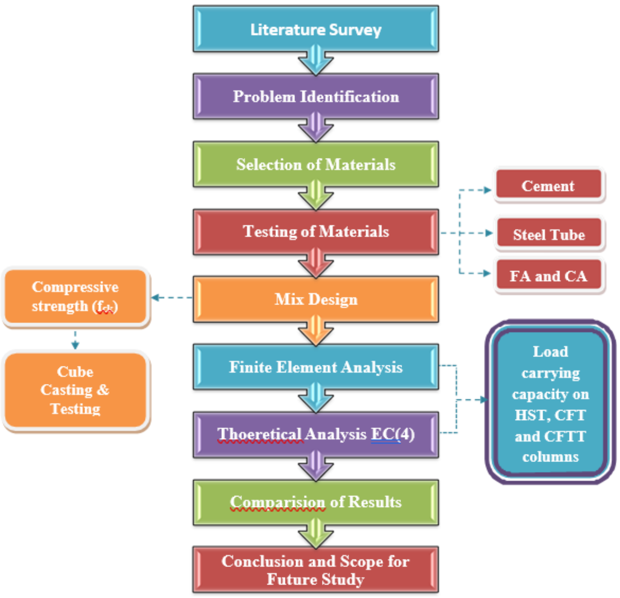


FIG I. FLOWCHART OF METHODOLOGY

A. *Experimental Investigation*

All circular tubes were fabricated with high yield strength of according to the code of Indian standard 1161. The thickness of the tube was measured by a screw-gauge at four places and the mean value was taken. Standard coupon test was conducted to determine the yield strength of the steel tube. Test coupons were cut from the steel tube section, and the testing procedure was done based on ASTM – A370. A dimension of tensile coupon test specimen. The yield strength of the steel tubes are 240 MPa, the modulus of elasticity is calculated to be 2 x 105 N/mm2. All tie bars were circular mild steel bars of diameter 3 mm with the yield strength of 250 MPa respectively.

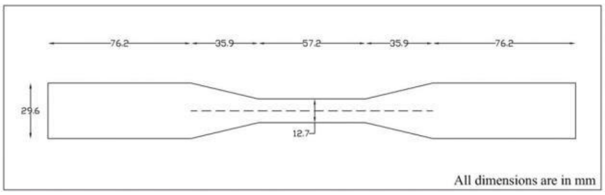


FIG II. STANDARD COUPON TEST SPECIMEN DIMENSION

TABLE I. MIX PROPORTION

Cement	**Fine aggregate**	**Coarse aggregate**	**Water**
1	1.65	2.67	0.55
378.18 kg/m^3	625.24 kg/m^3	1001.47 kg/m^3	208 liters

B. *Theoritical Analysis*

At present, there is no Indian Standard covering Composite Columns. The method of design suggested in this chapter largely follows EC (4), which incorporates the latest research on composite construction. This method also adopts the European buckling curves for steel columns as the basis of column design. It is formulated in such a way that only hand calculation is required in practical design. This method cannot be applied to sway columns. EC4 covers concrete encased and partially encased steel sections and concrete filled sections with or without reinforcement. This code uses limit state concepts to achieve the aims of serviceability and safety partial safety factor to loads and material properties.

The plastic compression resistance of a composite cross- section represents the maximum load that can be applied to a short composite column. Concrete filled circular tubular sections exhibit enhanced resistance due to the tri-axial confinement effects. Fully or partially concrete encased steel sections and concrete filled rectangular tubular sections do not achieve such enhancement.

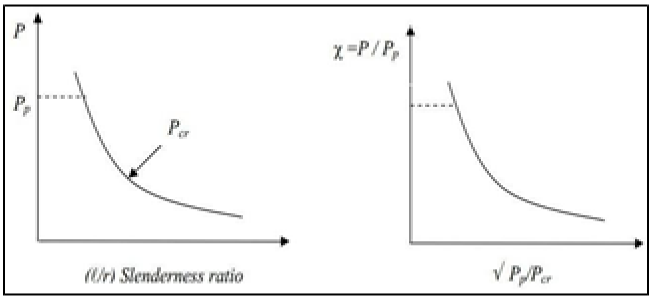


FIG III. IDEALIZED COLUMN BUCKLING CURVE & NON DIMENSIONALISED COLUMN

Practical columns have strength curves different from ideal columns due to residual stresses and geometric imperfections. The European buckling curves have been drawn after incorporating the effects of both residual stresses and geometric imperfections. They form the basis of column buckling design for both steel and composite columns in EC3 and EC4.

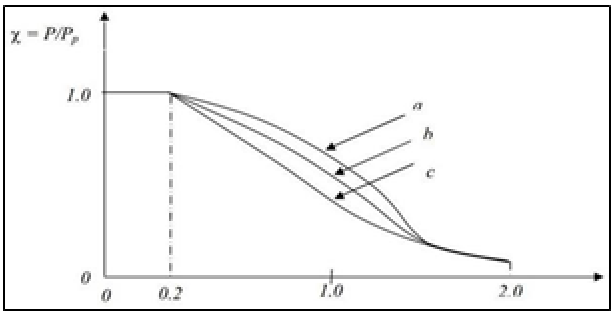


FIG IV. EUROPEAN BUCKLING CURVES

C. Numerical Analysis

In the present analysis, average stress strain curve obtained from material tests were used to model both steel and concrete core, assuming isotropy of the material. The behavior of the steel tube is simulated by an elastic perfectly plastic model. The material considered as mild steel for steel tube possessing yield strength (fy) of 240Mpa, mild steel for tie bars possessing yield strength (fs) of 250 Mpa elastic modulus (Es) of 200Gpa and for concrete elastic modulus (Ec) of 22360 Mpa. The elastic properties are completely defined by giving the Young's Modulus (E) and the Poisson's ratio (ν).

By isotropic hardening rule, multi linear stress strain curve was used to model steel. The main parameter for the multi linear stress strain curve is the experimentally measured yield stress (fy), the ultimate stress (fsu) and the ultimate strain (εsu). For steel, first part of the linear curve represents the elastic part up to the proportional limit stress with measured value of young modulus, Poisson's ratio equal to 0.3 and density as 7850kg/mm3. For concrete the Poisson's ratio (νc) of 0.2 and density as 2500kg/mm3.

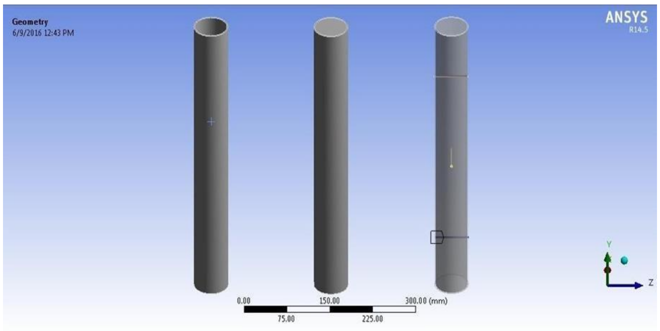


FIG V. GEOMETRY HST, CFT AND CFTT COLUMN SPECIMENS

Buckling analysis is carried out to obtain the Eigen modes, which were subsequently used to represent initial geometric imperfections. Buckling loads are critical loads where certain types of structures become unstable. Each load has an associated buckled mode shape; this is the shape that the structure assumes in a buckled condition. There are two primary means to perform a buckling analysis.

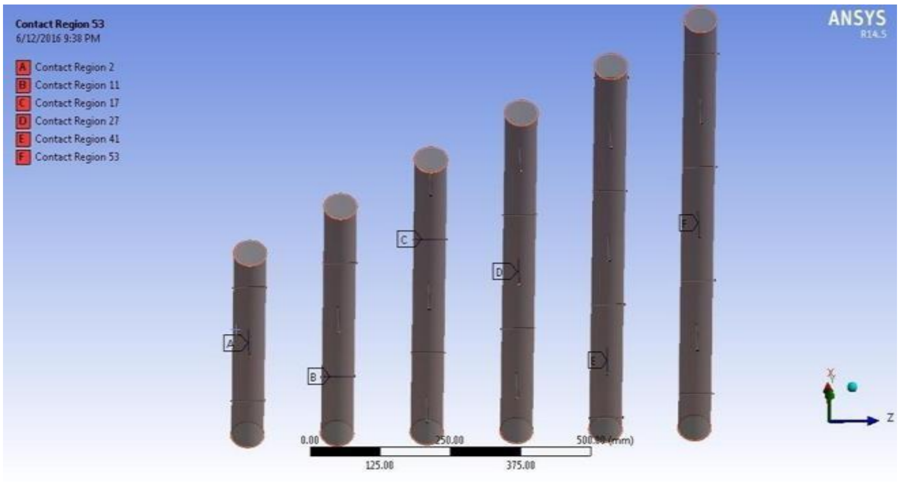


FIG V. TIE BARS CONTACT BETWEEN STEEL TUBE AND CONCRETE

Eigen value buckling analysis predicts the theoretical buckling strength of an ideal elastic structure. It computes the structural eigenvalues for the given system loading and constraints. This is known as classical Euler buckling analysis. Buckling loads for several configurations are readily available from tabulated solutions. However, in real- life, structural imperfections and nonlinearities prevent most real world structures from reaching their eigenvalue predicted buckling strength; i.e. it over-predicts the expected buckling loads. This method is not recommended for accurate, real-world buckling prediction analysis.

Nonlinear buckling analysis is more accurate than eigenvalue analysis because it employs non-linear, large - deflection, static analysis to predict buckling loads. Its mode of operation is very simple: it gradually increases the applied load until a load level is found whereby the structure becomes unstable (i.e. suddenly a very small increase in the load will cause very large deflections). The true non- linear nature of this analysis thus permits the modeling of geometric imperfections, load perterbations, material nonlinearities and gaps. For this type of analysis, note that small off-axis loads are necessary to initiate the desired buckling mode.

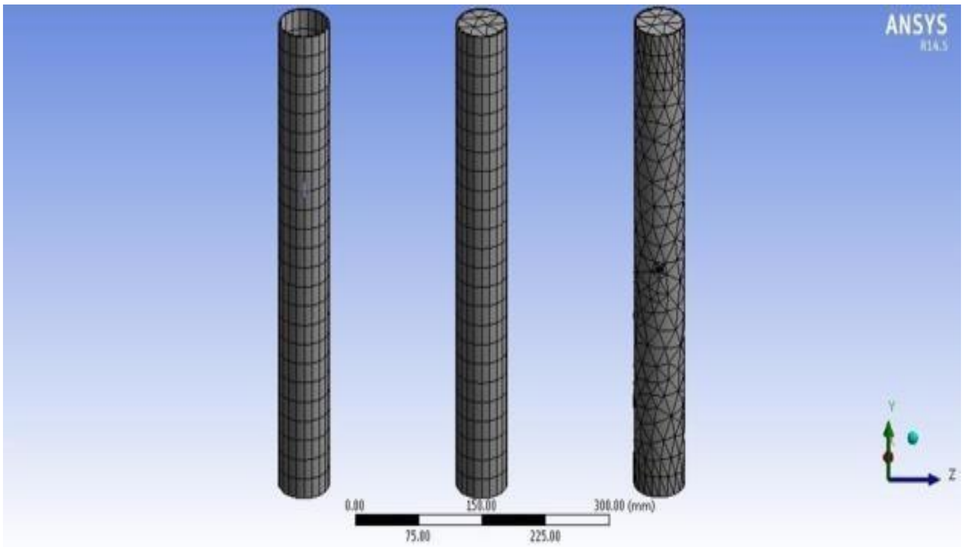
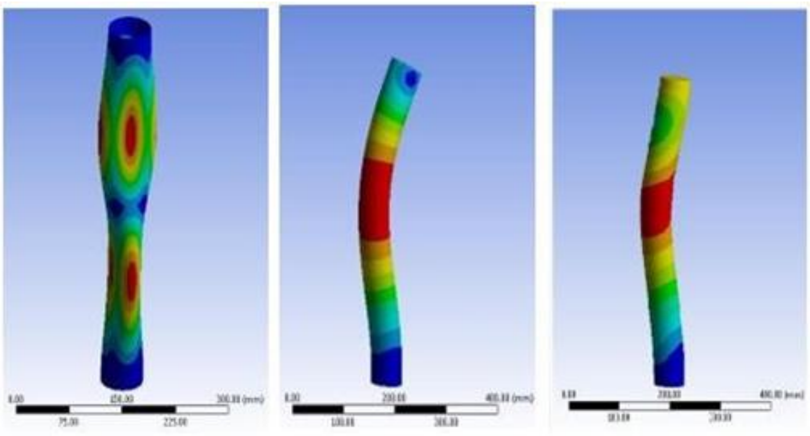


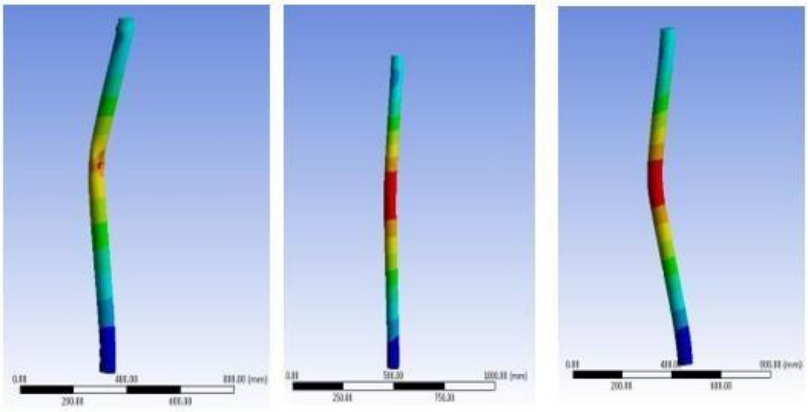
FIG VI. MESHING HST, CFT AND CFTT COLUMN SPECIMENS

First static analysis is performed and then procedure is changed to linear buckling analysis, which gives Eigen values. The first Eigen value is considered as buckling load factor critical load for linear analysis. First Eigen value because the column will break at the first load and there are less chance to go second critical load. But the material reaches nonlinearity action so therefore nonlinear analysis is performed. A nonlinear stress-strain value is introduced by selecting plasticity option in ANSYS. The first Eigen value is taken and is applied as load in this analysis by dividing it by number of nodes. Now job is created and submitted to run the analysis. The output gives a nonlinear graph which is plotted against load prediction verses deformation.



a) H.S.8 b) C.S.8 c) CT.S.8

FIG VII. FAILURE BEHAVIOR STUB COLUMNS A) INWARD BUCKLING, B) AND C) OUTWARD BUCKLING

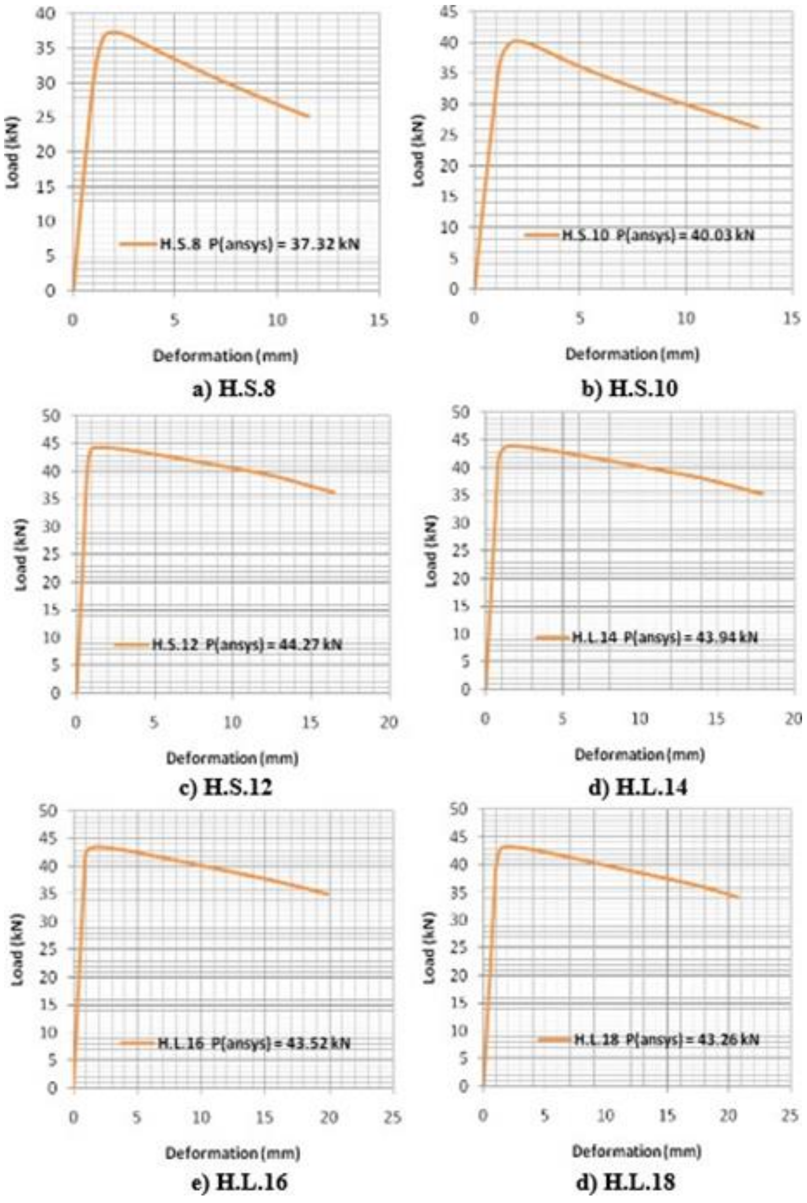


a) H.L.18 b) C.L.18 c) CT.L.8

FIG VIII. FAILURE BEHAVIOR SLENDER COLUMNS OUTWARD BUCKLING

Group	Specimen Detail	Ultimate Load Carrying Capacity of Columns (kN)		Loadratio PAnsys PEC(4)
		Numerical Analysis (kN) PAnsys	Theoretical Analysis (kN)PEC(4)	
1.	H.S.8	37.32	39.86	0.94
	H.S.10	40.03	40.64	0.98
	H.S.12	44.27	41.37	1.07
	H.L.14	43.94	42.01	1.05
	H.L.16	43.52	42.55	1.02
	H.L.18	43.26	42.95	1.01
	C.S.8	92.97	84.03	1.11
	C.S.10	91.15	79.72	1.14
	C.S.12	89.65	76.63	1.17
	C.L.14	88.37	74.64	1.18

2.	C.L.16	82.98	73.66	1.13
	C.L.18	81.73	73.53	1.11
3.	CT.S.8	94.02	88.01	1.07
	CT.S.10	92.55	83.67	1.11
	CT.S.12	89.65	83.24	1.08
	CT.L.14	87.82	81.34	1.08
	CT.L.16	86.42	83.18	1.04
	CT.L.18	83.40	83.18	1.00



a) H.S.8

b) H.S.10

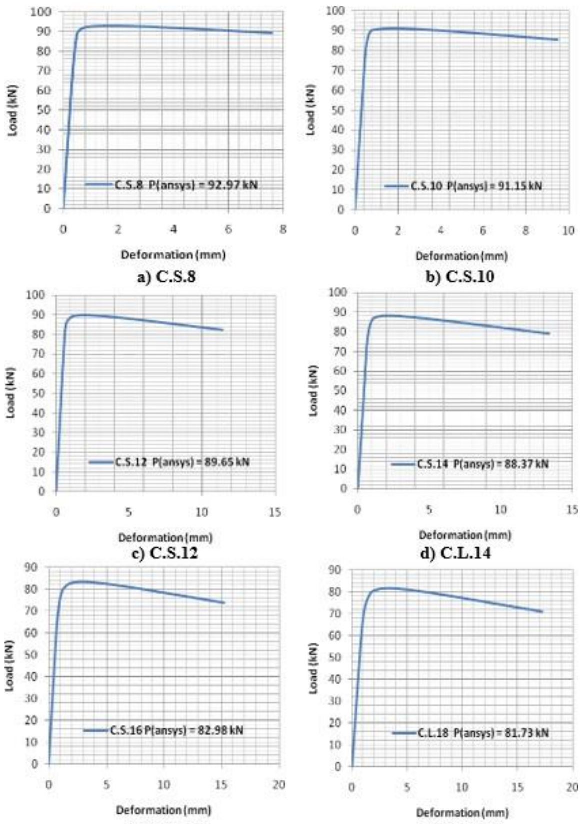
c) H.S.12

d) H.L.14

e) H.L.16

d) H.L.18

FIG IX. LOAD VERSES DEFORMATION CURVES FOR HST COLUMNS

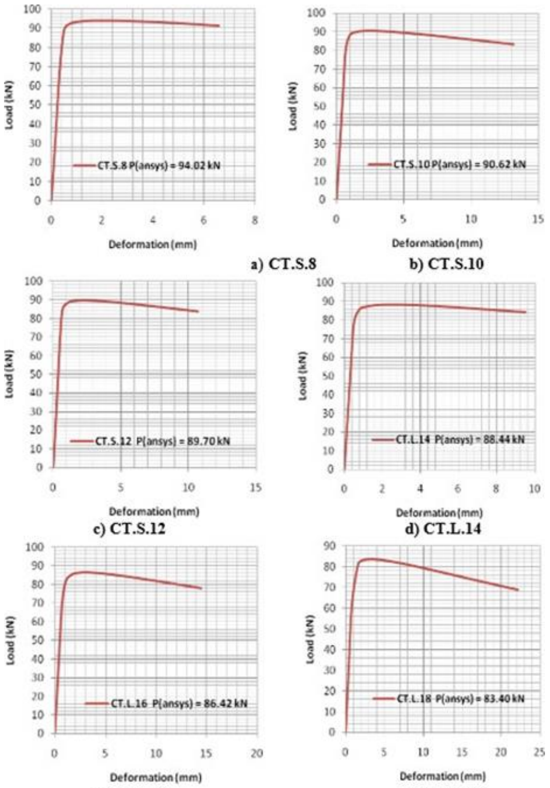


a) C.S.8 **b) C.S.10**

c) C.S.12 **d) C.L.14**

e) CT.L.16 **d) CT.L.18**

FIG X. LOAD VERSES DEFORMATION CURVES FOR CFT COLUMNS



a) CT.S.8 **b) CT.S.10**

c) CT.S.12 **d) CT.L.14**

e) CT.L.16 **d) CT.L.18**

FIG XI. LOAD VERSES DEFORMATION CURVES FOR CFTT COLUMNS

The hollow steel tube H.S.8 initially failed in global buckling mode and thereafter inward local buckling mode of failure at middle. The outward local buckling is observed in the C.S.8 column at the point in which the concrete crushing was expected to have occurred. In CFT column, confined concrete avoided the inward local buckling.

TABLE III. DEFORMATION VALUES OF COLUMNS UNDER NUMERICAL ANALYSIS

Group	Specimen Detail	Ultimate Lateral deformation	Ultimate Axial Shortening
		ΔAnsys	**ΔAnsys**
1.	H.S.8	1.57	2.34
	H.S.10	1.73	3.65
	H.S.12	1.87	4.52
	H.L.14	1.97	6.87
	H.L.16	2.37	8.15
	H.L.18	2.47	10.95
2.	C.S.8	1.79	2.25
	C.S.10	1.75	3.95
	C.S.12	1.92	4.21
	C.L.14	2.03	5.98
	C.L.16	2.23	7.12
	C.L.18	2.96	9.54
3.	CT.S.8	2.09	2.63
	CT.S.10	2.16	3.65
	CT.S.12	2.20	4.15
	CT.L.14	2.53	6.54
	CT.L.16	2.85	7.98
	CT.L.18	2.98	9.65

The effects of adding tie bars on the enhancement of axial load carrying capacity and the stiffness improvement are deliberate. It is evident from the table.2 that the addition of tie bars can improve the axial load carrying capacity (maximum, 3.98 %) of the CFT columns. This is because the tie bars can provide early confining pressure at the welded location and hence limit the lateral deformation of the steel tube and the core concrete to some extent.

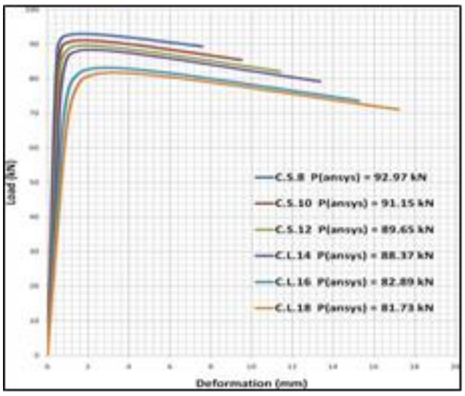


FIG XII. LOAD VERSES DEFORMATION CURVES COMPARISON FOR HST COLUMNS

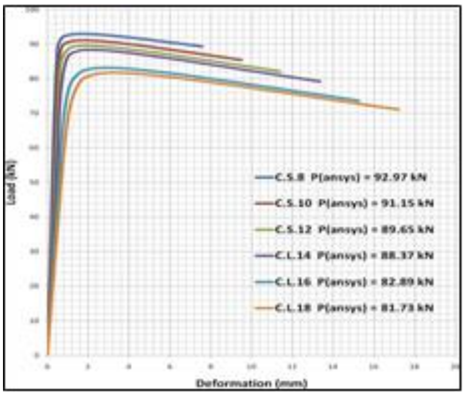


FIG XIII. LOAD VERSES DEFORMATION CURVES COMPARISON FOR CFT COLUMNS

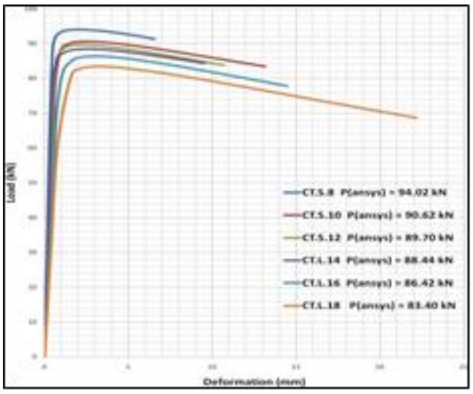


FIG XIV. LOAD VERSES DEFORMATION CURVES COMPARISON FOR CFT COLUMNS

A. Scope for Future Research

The present study can be extended for future research with consideration to the following points:

- In the present investigation to study the influence of load capacity and confinement circular sections of steel tube thickness 1.2 mm alone has been described.
- To validate the current study experimental investigations of these columns to be carry out.
- The study of confinement effect can be extended to comparison on various steel tube thickness can also be studied for different support conditions.
- Similarly the study of load capacity for varying slenderness ratios can be extended among the various sections.
- The study can also be extended to determine the confinement effects for various concrete grades.
- The study can also be extended to determine the load capacity and confinement effect for square and rectangular columns.
- Similarly the study of load capacity for CFT columns with different types shears connectors or ties bars.
- The study can also be extended to determine the load carrying capacity under eccentric loading.
- The study can also be extended to determine the moment of resistance under torsion effect.
- Similarly the study can also be extended on join connections (beam to column joints).
- The study can also be extended to determine the confinement effects for High performance concrete and High strength concrete.

V. CONCLUSION

- From numerical results, CFTT columns show higher ductility after maximum load. Tie bars could increase the axial load carrying capacity (maximum, 3.98 %) than the CFT columns.

- The results states that decrease in column slenderness increase the column axial load carrying capacity and increase in column slenderness decrease the column load carrying capacity.
- Even though, there is no significant increase in load carrying capacity of the concentrically loaded CFTT columns, such columns offer more ductility than the CFT columns. Hence, structures with CFTT can be used in seismic areas for improved structural behaviour.
- Finite element model results are obtained from ANSYS and compared with the theoretical results are significantly same.
- Increase in tie bars will increase the load carrying capacity of the columns.

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