Nonlinear Analysis of Circular Concrete Filled Steel Tube Columns under Axial Loading

Aditya Kumar Tiwary, Ashok Kumar Gupta

Abstract**:** ***Concrete filled steel tube (CFST) columns are composite member mainly consists of concrete infilled in steel tube. In current construction industry, CFST columns are preferred to provide lateral resistance in both unbraced and braced building structures. In this paper, finite element studies were carried out on concrete filled steel tube columns under an axial composite loading by using ABAQUS/CAE. The inelastic behavior of concrete and steel tube was defined to the model by using concrete damaged plasticity model (CDP) and Johnson-cook model respectively which is available in ABAQUS/CAE. The diameters of columns were considered as 100 mm, 125 mm and 150 mm, whereas the length of columns was kept constant, i.e. 600 mm for all models. The thickness of steel tube was considered as 4 mm and 5 mm for all diameters of columns. The concrete infilled of grade M30 was used in this study. The simulations were carried out against composite loading to study the response of CFST columns in terms of load carrying capacity, displacement and von-mises stresses. The mesh conversion study was also carried out to obtain the best size of mesh corresponding to the experimental load carrying capacity of CFST columns.***

Keywords: CFST columns, non-linear behavior, finite element study.

I. INTRODUCTION

Concrete filled steel tube (CFST) columns have been broadly used in high-rise buildings due to their excellent resistance to axial load. In concrete filled steel tube columns, the outer steel tubes act as a formwork for pouring concrete and therefore, it eliminates the requirement of extra formwork which decreases the construction cost and time [1–8]. Also, the concrete filled steel tube column with placement of outer steel tube replaced the embedded reinforcement in concrete. Hence, CFST columns are extensively used as columns in large span high rise buildings, bridges and piers [2, 3, 9, 10]. In previous investigations, it has been concluded that the ductility of CFST columns can be enhanced by concrete confinement [11] and it also performs better than RCC columns [12, 13, 15]. As the Poisson's ratio of concrete is not as much as steel (0.18 and 0.3 individually) at the underlying flexible stage, the hoop stress in steel cylinder is very little and becomes observable when dilatency of concrete is bigger than previously and ends up inelastic [21]. Attributable to this variety in stresses and Poisson's ratio delamination of concrete from steel turns into a lasting issue which diminishes the adequacy of imprisonment of concrete [18].

When we apply tensile stresses on CFST composite of these two materials, steel can demonstrate more strain than concrete. Because of this, a study was led to analyze the debonding impact on CFST and inferred that the occurrence of local buckling in a circular steel tube in debonding, specimens was considerably more extreme than that of example without debonding [16]. Bond conduct in concrete filled steel tube was additionally contemplated by performing push-out examination on CFST examples [17]. It was reasoned that the bond quality among concrete and steel tube could be upgraded by giving the welded steel rings onto the internal surface of steel tube. Welding shear studs and concrete have similarly been wound up being good techniques to improve the bond strength after welding inward steel rings.

II. FINITE ELEMENT MODELLING

A finite element model of CFST columns were made by using ABAQUS/CAE. The inelastic behavior of outer steel tube was defined by using Johnson cook model and for concrete by using concrete damaged plasticity model (CDP) available in ABAQUS/CAE. To create a model of CFST columns, the geometry of CFST columns are shown in table 1 and 2.

Table-I: Geometry of CFST columns

Specimens	Outer Diameter (mm)	Thickness of steel (mm)	Height (mm)	D/T	L/D
C1T4	100	4	600	25	6.0
C1T5	100	5	600	20	6.0
C2T4	125	4	600	31	4.8
C2T5	125	5	600	25	4.8
C3T4	150	4	600	37	4.0
C3T5	150	5	600	30	4.0

Table-II: Area of infilled concrete and outer steel tubes

Specimens	Area (mm^2)		
	Steel (As)	*Concrete (Ac)*	*Total*
C1T4	1206	7234	8441
C1T5	1492	7084	8577
C2T4	1520	11493	13013
C2T5	1885	11304	13189
C3T4	1834	16733	18567
C3T5	2277	16504	18782

A. Description of finite element modeling

The model was based upon the concept of isotropic damaged elasticity to represent the inelastic behavior of concrete. The compressive strength of concrete was 30 MPa. The Poisson's ratio of concrete and steel was assumed equal to 0.18 and 0.3 respectively.

Revised Manuscript Received on September 05, 2019.

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The outer steel tube behavior of CFST columns were consolidated by using Johnson cook elasto viscoplastic model that is able to anticipate the fracture behavior of ductile materials. It introduce the effect of strain rate hardening, yielding, linear thermo elasticity, isotropic strain hardening, plastic flow, softening due to adiabatic heating and damage. The concrete damaged plasticity model was used to incorporate the behavior of infilled concrete under composite loading. The CDP model defines the behavior of concrete under multi-axial loading conditions.

- *Element types:* The numerical simulation was performed by using commercial finite element tool ABAQUS/CAE. The mesh sensitivity in CFST columns was studied by varying the element size in the entire region of columns throughout the height. The element size of infilled concrete core was considered as 10 mm, 20 mm and 30 mm whereas; the size of the element in outer steel tube was kept constant, 100 mm for entire simulations. Typical finite element model of concrete core and outer steel tube element are shown in fig. 1 (a) and (b) respectively. The meshing of infilled concrete core and outer steel tube are shown in fig. 2 (a) and (b) respectively.

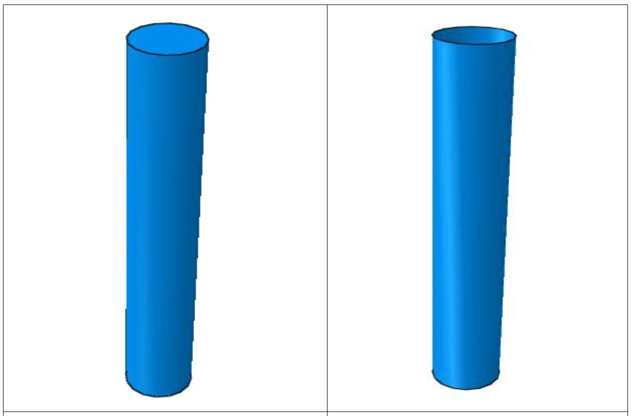
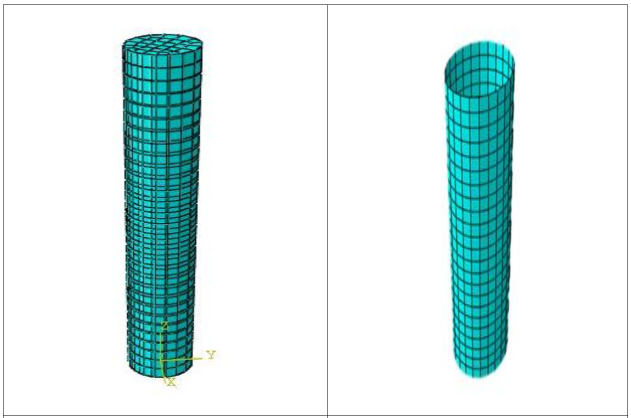

(a) Infilled concrete core (b) Outer steel tube

Fig. 1. Modeling of infilled concrete core and outer steel tube



(a) Infilled concrete core (b) Outer steel tube

Fig. 2. Meshing of infilled concrete core and outer steel tube

- Boundary conditions: The boundaries of two ends were restrained with respect to all the degree of freedom. The interaction between outer steel tube and concrete core has modeled using the tie constraint option available in ABAQUS/CAE.
- Interactions between outer steel and concrete core: The surface to surface interaction between concrete core and outer steel tube with tangential behavior was considered. The stiffness method allows the relative movement between the surfaces of two materials even when they are pushing. The magnitude of slip was limited to elastic slip while they are sticking ($\tau \leq \tau\text{crit}$). The interaction between outer steel tube and concrete core are shown in fig. 3.

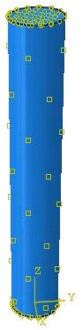


Fig.3. Interaction model between outer steel and concrete core

B. Material modeling

- *Steel:* In order to define the material properties of steel, the behavior of steel tube was defined to the model by using Johnson cook model available in ABAQUS/CAE. The thickness of steel tube was considered as 4 mm and 5 mm for all diameters of columns. The Poisson's ratio of steel was assumed equal to 0.3. The behavior of outer steel tube was incorporated by using the Johnson cook elasto-viscoplastic model that is capable of predicting the fracture behavior of the ductile materials.
- *Concrete*: The diameters of concrete core were considered as 100 mm, 125 mm and 150 mm, whereas the height was kept constant, 600 mm for all models. The compressive strength of concrete was 30 MPa. The Poisson's ratio of concrete was assumed equal to 0.18. The behavior of infilled concrete under axial composite loading was incorporated by using the concrete damaged plasticity model. The CDP model defines the behavior of concrete under multi-axial loading conditions.

C. Validation of results

For the validation of results, the experimental results were compared to the analytical results obtained for the different mesh size 10, 20 and 30 mm in terms of load carrying capacity, displacement and stresses. The load carrying capacity of C1T4 concrete filled steel tube column with mesh size of 10, 20 and 30 mm was found to be 858, 843 and 875 kN respectively. The load carrying capacity of C1T4 concrete filled steel tube column was obtained experimentally i.e. 834 kN and was found a great concurrence with the predicted load of 843 kN corresponding to mesh size of 20 mm. The outcomes showed that the observed load carrying capacity of C1T4 concrete filled steel tube column by finite element modeling was in great concurrence with the experimental observed values corresponding to the mesh size of 20 mm. Therefore, it is concluded that the mesh size of 20 mm across cross section of the concrete filled steel tube column was considered for conducting remaining simulations of the model C1T5, C2T4, C2T5, C3T4 and C3T5.

III. RESULTS AND DISCUSSION

The extensive numerical simulation was performed on concrete filled steel tube columns against static composite loading for all specimens such as C1T4, C1T5, C2T4, C2T5, C3T4 and C3T5. The parameters such as load carrying capacity, displacement and stresses in concrete filled steel tube columns were studied for all columns against axial composite loading. The results obtained in terms of load carrying capacity, displacement and stresses on the outer steel tube and infilled concrete core were compared and presented in detail.

A. Load carrying capacity of concrete filled steel tube columns

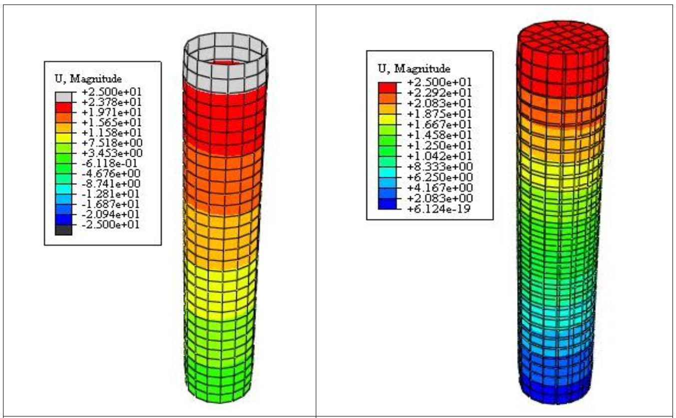
The diameter of CFST column varied as 100 mm, 125 mm and 150 mm and the outer steel thickness 4 mm and 5 mm for all three CFST columns was considered in this present investigation. The load carrying capacity of CFST column was increasing with increase the diameter of circular columns as listed in table 3. The results obtained from the simulation showed that the observed load carrying capacity of concrete filled steel tube column by finite element modeling was in great concurrence with the experimental observed values corresponding to the mesh size of 20 mm.

Table-III: Comparison of load carrying capacity of CFST columns

Sample	Size (D X Ts X H mm)	Experimental load capacity (kN)	Simulated Load Capacity (kN)
C1T4	100 X 4 X 600	834	843
C1T5	100 X 5 X 600	836	849
C2T4	125 X 4 X 600	1252	1261
C2T5	125 X 5 X 600	1263	1268
C3T4	150 X 4 X 600	1749	1756
C3T5	150 X 5 X 600	1768	1774

B. Deformation in concrete filled steel tube columns

The graphical representation of the obtained results of the specimens C1T5, C2T4, C2T5, C3T4 and C3T5 showed that the two curves are close to each other as shown in figure 5 to 10. In the present study the deformation of the concrete filled steel tube columns was increased with respect to the loading. It may be due to the large area of application of axial composite loading. The concentration of deformation was found to be decreased linearly towards bottom of the column and highest deformation was found at the top of column. The variation of the results between analytical and experimental was potentially emerged from the distinction in the material property, site condition and defect between the test samples and finite element models.



(a) Deformation in steel (b) Deformation in concrete

Fig. 4 Deformation in steel and concrete

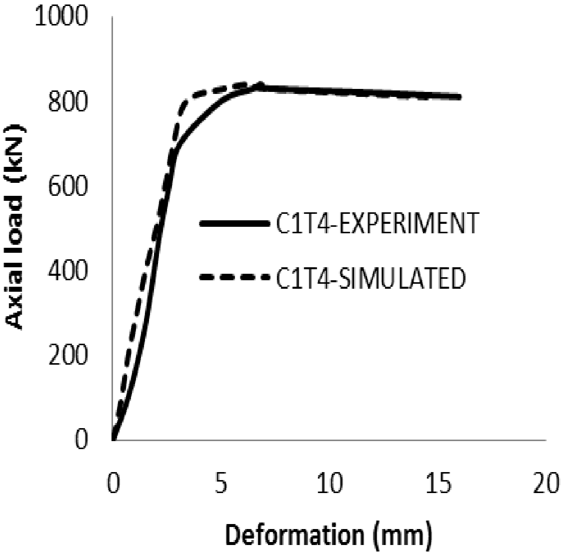


Fig.5. Experiment Vs. simulated load-deformation curve for C1T4 column

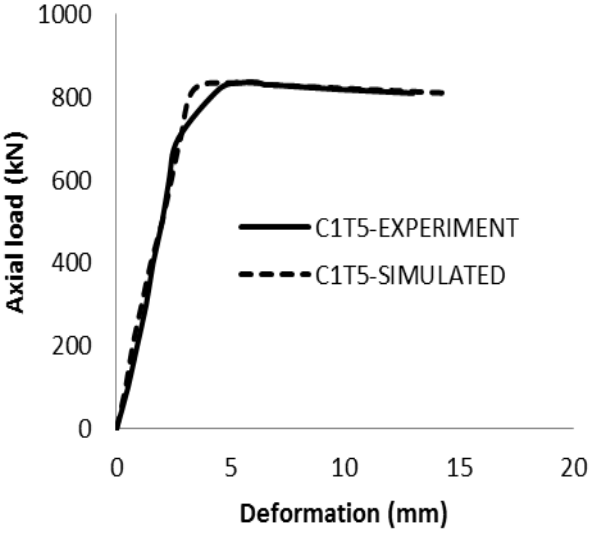


Fig.6. Experiment Vs. simulated load-deformation curve for C1T5 column

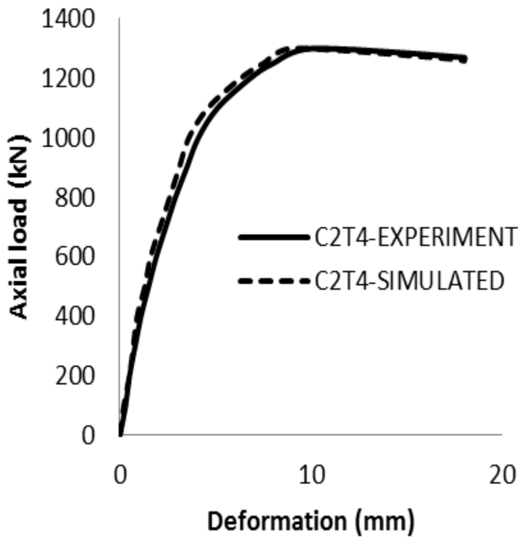


Fig.7. Experiment Vs. simulated load-deformation curve for C2T4 column

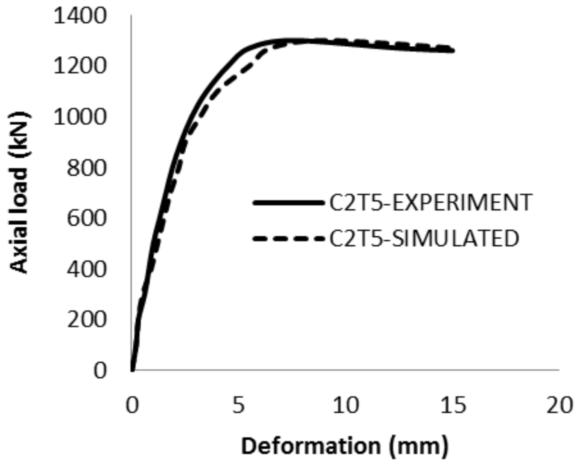


Fig.8. Experiment Vs. simulated load-deformation curve for C2T5 column

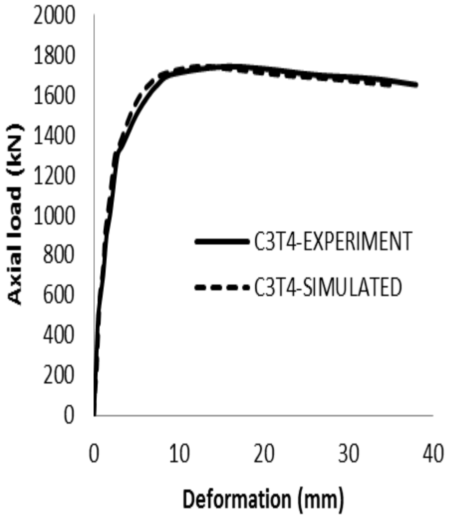


Fig.9. Experiment Vs. simulated load-deformation curve for C3T4 column

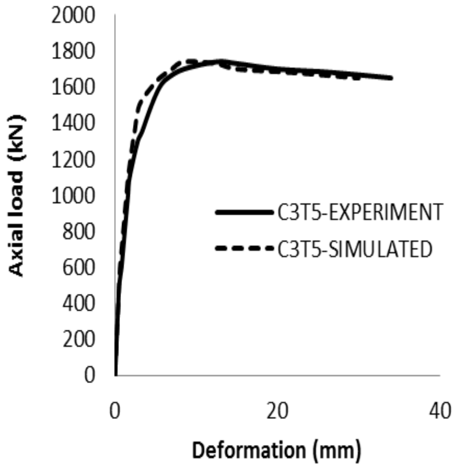
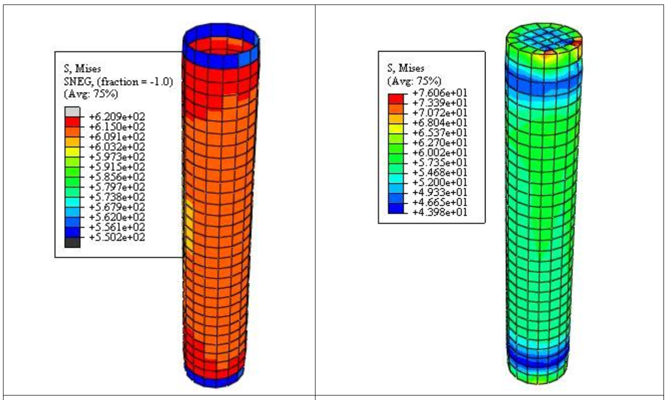


Fig.10. Experiment Vs. simulated load-deformation curve for C3T5 column

C. Stress in concrete core and outer steel tube of concrete filled steel tube columns

The stress in the concrete core and outer steel tube was obtained by numerical simulation by using ABAQUS/CAE for all specimens are listed in table 4. The stress in outer steel tube was found more as compare to the stress in concrete core as shown in fig. 11 (a) and (b).



(a) Von-mises stress in steel (b) Von-mises stress in concrete

Fig. 11 Von-mises stress in steel and concrete

Table-IV: Stress behavior of concrete core and outer steel tube

Specimens	Size (D X Ts X H mm)	Stress in concrete core (MPa)	Stress in outer steel tube (MPa)
C1T4	100 X 4 X 600	116.5	698.8
C1T5	100 X 5 X 600	119.8	568.9
C2T4	125 X 4 X 600	105.8	829.3
C2T5	125 X 5 X 600	112.2	672.7
C3T4	150 X 4 X 600	104.9	957.1
C3T5	150 X 5 X 600	107.5	778.9

IV. CONCLUSIONS

The present numerical study describes the non-linear behavior of concrete filled steel tube columns subjected to axial composite loading. The simulation was carried out by using ABAQUS/CAE. The response of CFST columns with varying size of concrete core and thickness of outer steel tube were studied and compared with the experimental results. The results thus obtained through finite element investigations led to the following conclusions;

1) The load carrying capacity of concrete filled steel tube column was increased with increase in diameter of CFST columns. It was observed that with the change in thickness of outer steel tube from 4 mm to 5 mm, the load carrying capacity of CFST columns were almost same. The load carrying capacity obtained by finite element modeling was in great concurrence with the experimental observed values corresponding to the mesh size of 20 mm.
2) The deformation of CFST columns with diameter 100 mm, 125 mm and 150 mm (L/D ratio between 6 and 4) were found to be increased almost linearly.
3) The stresses obtained in concrete core element of the column C1 with diameter 100 mm was maximum 119.83 MPa as compared to 125 mm and 150 mm diameter columns. The stresses in the outer steel tube were found maximum 957.11 MPa for the column C3 with the outer steel thickness of 4 mm. It was also observed that the stresses in CFST columns decreased with increase in the thickness of outer steel tube from 4 mm to 5 mm.

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