Analytical Study on Behaviour of Concrete Filled Steel Tubular Columns

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ABSTRACT
The Finite Element method allows complex analysis of the nonlinear response of concrete filled steel tubular columns to be carried out in a routine fashion. FEM helps in the investigation of the load deflection behaviour of the structure. In the present study, the nonlinear response of concrete filled steel tubular column using FE modelling under the axial loading. The non-linear analysis of the columns with infilled and without infilled concrete were analysed by varying the slenderness ratio (40, 50 and 60) and concrete strength (M15, M25 and M35). It was found that the enhancement of strength in the case of Concrete Filled Steel Tubular Column depends on the compressive strength of filled concrete and on the confinement effect. The overall percentage decrease in the deflection of CFST column for varying slenderness ratio and strength of the concrete has been studied.

KEYWORDS: Concrete Filled Steel Tubular Column, ANSYS, Strength enhancement, Confinement effect, decrease in deflection

INTRODUCTION

[1] presented non-linear finite element study on circular concrete filled steel tubular columns. In this research modeling of 11 circular cross-section model of the columns, these models are taken from pre-publication research, the models been simulated nonlinearly by the finite element method, with the help of the ANSYS software. Models have been loaded in a concentric axial compression way, the failure loads were extracted, and have been compared to the results obtained from the experimental data. It been found from the nonlinear modeling by ANSYS program a significant influence of the proportion of the D/t ratio on the axial load capacity of the concrete filled steel tubular, where concluded that the axial load capacity of the columns increases significantly when lowering the value of the of D/t under the value 47, but when increasing the value of the D/t over 47 the axial load capacity of the columns increases in small rates. All the specimens been simulated had the length to diameter ratio (L/D) not exceeding the value of 4.5 to act as a short column, and, therefore, no slenderness effect would be taken in account. It was found that results of the experimental test and the simulation showed good agreement. Concrete filled steel tubular columns axial capacity significantly affected with the cross-section of the column, concrete compressive strength and yield strength of the steel tubes.

[2] presented a non-linear finite element model used to predict the behavior of slender concrete filled steel tubular columns with elliptical hollow sections subjected to axial compression. The accuracy of the FEM was validated by comparing the numerical prediction against experimental observation of eighteen elliptical CFST columns which widely represent typical section sizes and member slenderness. In total, eighteen slender
elliptical CFST columns, with two hollow section sizes (150mm x 75mm x 4mm, 200mm x 100mm x 5mm), three column lengths (1.5m, 1.8m and 2.5m) and three nominal concrete strength (30, 60 and 100 MPa) were tested to investigate the axial compressive behavior and failure modes. The adaptability to apply the current design rules provided in Eurocode 4 for circular and rectangular CFST columns to elliptical CFST columns were discussed. Finite element model was developed by ABAQUS software in order to validate the results with experimental results. A parametric study was carried out with various section sizes, lengths and concrete strength in order to cover a wider range of member cross-sections and slenderness which is currently used in practices to examine the important structural behavior and design parameters, such as column imperfection, non-dimension slenderness and buckling reduction factor, etc. Both experimental and numerical modeling results demonstrated that the failure mode of a slender CFST column under compressive loads was global buckling with the first buckling mode shape. It was conclude that the simplified design method provided in Eurocode 4 may be used for axial compressive behavior design of elliptical CFST columns and the initial imperfection has a significant effect to the axial compressive behavior of slender elliptical CFST columns. Initial imperfection of Le/2000 should be used for the FE modeling. Where Le was effective length of the concrete filled steel tubular column. It was also concluded that the design rules given in Eurocode 4 for circular and rectangular CFST columns may be adopted to calculate the axial buckling load of elliptical CFST columns although using the imperfection of length/300 specified in the Eurocode 4 might be over- conservative for elliptical CFST columns with lower non-dimensional slenderness.

[3] investigated the behavior of concrete filled steel columns. In the this paper, experimental results of concrete–filled steel columns and polymer modified concrete filled steel columns under axial load combined with lateral cyclic loading were reported. Circular CFST model columns with steel tube diameter-thickness ratio (D/t) of 57 were tested to failure. This ratio satisfies the limitations specified by various codes. The yield stress and ultimate stress of steel section were found to be 270N/mm² and 410N/mm² respectively and the percentage elongation was 13% and modulus of elasticity was 2.05 × 10⁵ N/mm². The design mix of 1:2.09:2.25 with a w/c ratio of 0.49, using 12.5mm size (max.) coarse aggregate and 2.36mm (max.) size fine aggregate was used as per ACI committee 211.1.1991 recommendations. The PCC (Portland cement concrete) and PMC (polymer modified concrete) for the composite columns were mixed in two separate batches. To assess the compressive strength, cubes of size 150 mm x 150 mm x 150 mm and cylinders of size 300mm x 150mm were cast. It was found that Polymer modified concrete filled steel columns fail in a ductile manner and exhibit pump hysteretic loops with a slight pinching effect under the combination of axial load and lateral cyclic load. Polymer modified concrete filled columns exhibit high ductility with moderate axial strength increase, an attribute that has become of great necessity in currently emphasized ductility oriented seismic design.

[4] conducted the test on steel columns filled with normal concrete and lightweight concrete were carried out to investigate the actual behavior and the load carrying capacity of such columns. Eight full scale rectangular cross-section columns filled with lightweight aggregate concrete and normal weight aggregate concrete, four specimens each, were tested under axial loads for comparison purposes. Sections filled with lightweight aggregate concrete failed due to local as well as overall buckling, and they supported more than 92% of the squash load. Sections filled with normal weight aggregate concrete failed due to overall buckling at mid height, and they supported more than 87% of the squash load. It can obviously be seen that columns with lightweight aggregate concrete filled steel tubular support similar loads as columns filled with normal weight aggregate concrete. On the other hand, the weight of the column with lightweight concrete was 30% less than that of the column with normal concrete of the same cross-section. It can obviously be seen that columns with lightweight aggregate concrete filled steel tubular support similar loads as columns filled with normal weight aggregate concrete. On the other hand, the weight of the column with lightweight concrete was 30% less than that of the column with normal concrete of the same cross-section. Hence the results showed that using lightweight concrete filling instead of normal concrete filling will reduce the weight of columns. At the same time, a high load carrying capacity is achieved.

[5] presented experimental and computational study on the behavior of circular concentrically loaded concrete filled steel tube columns till failure. Eighty- one specimens were tested to investigate the effect of diameter and D/t ratio of a steel tube on the load carrying capacity of the concrete filled tubular columns. The effect of the grade of concrete and volume of flyash in concrete was also investigated. The effect of these parameters on the confinement of the concrete core was also studied. Diameter to wall thickness ratio between 25 < D/t < 39, and the length to tube diameter ratio of 3 < L/D < 8 was investigated. Strength results of Concrete Filled Tubular columns were compared with the corresponding findings of the available literature. Also a nonlinear finite element model was developed to study the load carrying mechanism of CFSTS using the Finite Element software ANSYS. This model was validated by comparison of the experimental and computational results of load–deformation curves and their corresponding modes of collapse. The displacement at the yield point is found to be 2–3 mm (about 20%–30%) less in the case of the computational graphs when compared with the experimental one for all types of specimens From the experimental and computational study it
was found that for both modes of collapse of concrete filled tubular columns at a given deflection the load carrying capacity decreases with the increase in % volume of flyash up to 20% but it again increases at 25% flyash volume in concrete.

[6] presented the paper on finite element analysis of CFST columns subjected to an axial compressive force and bending moment in combination. Proper material constitutive models for concrete filled steel tube (CFST) columns subjected to an axial compressive force and bending moment in combination are proposed and verified in this paper by using the nonlinear finite element program ABAQUS compared against experimental data. In the numerical analysis, the cross sections of the CFST columns are categorized into three groups, i.e., ones with circular sections, ones with square sections, and ones with square sections stiffened with reinforcing ties. In the analysis, the Poisson’s ratio μs and the elastic modulus ES of the steel tube are assumed to be 0.3 and 200 GPa, respectively. In this study, the Poisson's ratio of concrete is assumed to be 0.2. The uniaxial behavior of the steel tube is similar to that of the reinforcing tie and thus can be simulated by an elastic–perfectly plastic model. It is shown that the steel tubes can provide a good confining effect on the concrete core when the axial compressive force is large. The confining effect of a square CFST stiffened by reinforcing ties is stronger than that of the same square CFST without stiffening ties but weaker than that of a circular CFST. However, when the spacing of reinforcing ties is small, a CFST with a square section might possibly achieve the same confining effect as one with a circular section.

[7] presented the numerical part of the research program on concrete-filled steel columns. Nonlinear, three dimensional FE analysis of axial compression, was conducted using the finite element program ABAQUS. Four steel tube columns were taken in which two were without concrete and other two were filled with concrete. The numerical results were validated through comparison with experimental data in terms of ultimate loading and deformation modes. To avoid numerical problems the inelastic material response should be approximated by curves with a limited number of points. The magnitude of the yield stress is critical for ultimate load estimation. The effect of residual stresses due to welding of the side plates was not taken into account in the presented research. Imperfections in the form of loading eccentricity do not reduce the ultimate load significantly but can change the deformation pattern. This explains the variation of deformation obtained in the experiment. The effect of imperfections highlights the importance of precise measurements before testing to evaluate the actual geometrical imperfections. Modeling related problems such as the definition of boundary conditions, imperfections, concrete-steel interaction, material representation and others are investigated using a comprehensive parametric study. The developed FE models will be used for an enhanced interpretation of experiments and for the predictive study of cases not included in the experimental testing.

[8] investigated the behavior of short concrete filled steel tube columns concentrically loaded in compression to failure. Experimental and analytical study was carried out to find the behavior of concrete filled steel tube columns. Fourteen specimens were tested to investigate the effect of the steel tube shape and wall thickness on the ultimate strength of the composite column. Length of all columns was same. Depth-to-tube wall thickness ratios between $17 < D/t < 50$, and the length-to-tube depth ratios of $4 < L/D < 5$ were investigated. Ultimate strength results were compared to current specifications governing the design of concrete-filled steel tube columns. Nonlinear finite-element models were developed by using ABAQUS software and verified these analytical results with experimental results. The concrete core of the concrete filled steel tube columns was modeled using 20-node brick elements, with three translation degrees of freedom at each node and steel tube was modeled using an 8-node shell element, with five degrees of freedom at each node. The three-dimensional concrete material model available in ABAQUS was developed to simulate conditions with uniaxial strain and relatively low confining pressure. The analytical models were further used to investigate the adequacy of design specifications. Experimental results suggest that circular tubes offer substantial post-yield strength and stiffness, not available in most square or rectangular cross sections. Also observed by these results was that current design specifications were adequate to predict the yield load under most conditions for a variety of structural shapes.

[9] studied the behavior of slender square concrete filled stainless steel columns subjected to the axial load. Due to its excellent corrosion resistance, decorative qualities, ease of maintenance and fire resistance, the past few decades have seen the accelerating interest in the use of stainless steel in construction throughout the world. A total of 6 square concrete filled steel tubular columns were tested under axial loading to evaluate the influence of global slenderness. Two concrete grades were used having concrete cylindrical strength of 36.3 MPa and 75.4 MPa and slenderness ratio limits from15.2 to 87.7. Several existing design codes, including the Australian design code AS 5100 (2004), American code AISC (2005), Chinese code DBJ 13-51-2003 (2003) and Eurocode 4 (2004), are used to predict the column strength and are compared with the test results. This is helpful in evaluating the applicability of the current codes in calculating the strength of slender square concrete filled stainless steel tubular columns. It was found that the larger the slenderness ratio the smaller the peak load is. As stainless steel tube was used to compare the results between carbon steel and stainless steel. As there was no obvious difference between carbon steel and stainless steel tubes in terms of test observations and failure modes. Composite action between steel tube and concrete core still exists for slender concrete filled
stainless steel columns, but this action decreases with increasing slenderness ratio. Slenderness reduction factors should be applied in designing slender concrete filled stainless steel columns.

Objectives:
The aim of the study was to determine the optimum solution with reference to strength of the column, size, in-filling material, L/D ratio, etc. This paper compared the hollow steel columns, as well as concrete-filled columns, with different types of grade of concrete.

MATERIALS AND METHODS

1. Methodology:
   ○ Choosing Element type
   ○ Property – Create and assign material properties
   ○ Modeling – Hollow steel tube and Concrete infill
   ○ Meshing
   ○ Load – Define and place all loads and boundary conditions
   ○ Solution Analysis

1.1 Steps For Modeling And Analysis
1.1.1 Preprocessing:
   • Choosing Element type
   • Property – Create and assign material properties
   • Modeling – Hollow steel tube and Concrete infill
   • Meshing
   • Load – Define and place all loads and boundary conditions
   • Solution Analysis

1.2 Element type:
1.2.1 STEEL TUBE (Element type 1):
   SHELL93 is particularly well suited to model curved shells. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes. The deformation shapes are quadratic in both in-plane directions. The element has plasticity, stress stiffening, large deflection, and large strain capabilities.

![](Fig_1.png)

**Fig. 1:** SHELL93 Geometry

1.2.2 Infilled Concrete (Element type 2):
   SOLID 186 is used to model the infilled concrete. It is a higher order 3-D 20-node solid element that exhibits quadratic displacement behavior. The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. The element supports plasticity, hyperelasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyperelastic materials. They use the uniform reduced integration method or the full integration method, as follows:
   • Uniform reduced integration method
     Helps to prevent volumetric mesh locking in nearly incompressible cases. However, hourglass mode might propagate in the model if there are not at least two layers of elements in each direction.
   • Full integration
     The full integration method does not cause hourglass mode, but can cause volumetric locking in nearly incompressible cases. This method is used primarily for purely linear analyses, or when the model has only one layer of elements in each direction.
SOLID186 is available in two forms:

- Homogenous Structural Solid
- Layered Structural Solid

![Homogeneous Structural Solid](image)

**Fig. 2: Homogeneous Structural Solid**

**1.3 Material Properties:**

**1.3.1 Steel:**
- The young’s Modulus $E = 2 \times 10^5$ MPa
- Poisson’s ratio $\nu = 0.3$

**1.3.2 Concrete:**
- The young’s Modulus $E = 5000 \sqrt{f_{ck}}$
- Poisson’s ratio $\nu = 0.2$

![Material Property for Element 1](image)

**Fig. 5: Material Property for Element 1**

![Material Property for Element 2](image)

**Fig. 6: Material Property for Element 2**
1.4 Modeling:
Use ANSYS Software to create a three-dimensional model of the circular hollow tube section (CHS) structures under externally applied axial loading. The circular tube is constructed of 3.2 mm thick steel and is 60.3 mm of outer diameter. The length of the tube could be 800 mm for analysis.

The modeling has been done using finite element analysis of ANSYS software. The input are:
- Outer diameter = 60.3 mm
- Inner diameter = 53.9 mm
- Thickness = 3.2 mm
- Length = 800 mm, 1000 mm and 1200 mm
- Yield stress = 250 N/mm²
- Young’s modulus = 2 x 10⁵ N/mm²
- Poisson ratio = 0.3

Figure 7 and 8 shows the model of the specimens developed using ANSYS.

Fig. 7: Model without infill  
Fig. 8: Model with Infill

1.5 Meshing:
- Set mesh global size value to 10.
- Element type 2 is meshed with respect to volume
- Element type 1 is meshed with respect to area

Figure 9 shows the finite element and mesh model of the Column without in filled concrete. Figure 10 shows the finite element and mesh model of the Column without in filled Concrete. Figure 11 shows the loading and boundary condition of the model.

Fig. 9: Mesh Model of the Column Without fill  
Fig. 10: Mesh Model of the Column with infill

1.6 Loading and Boundary Conditions:
The columns are fixed at the one end. The axial load is applied at the other end in the downward direction. It is allowed to displace in vertical direction.
2. Computer Modeling Of Composite Column:
The behavior of Non composite and composite columns can also be analysed using Finite element analysis (FEA). FEA, as used in structural engineering, determines the overall behavior of a structure by dividing it into a number of simple elements, each of which has well-defined mechanical and physical properties.

Modeling the complex behavior of Composite column, which is both non homogeneous and anisotropic, is a difficult challenge in the Finite element analysis of civil engineering structures. The non-linear analysis of bond strength between concrete and steel, failure due to crushing of concrete in CFT columns and elephant foot buckling at the top and bottom of the CFT columns is very complicated in nature. Hence Finite Element Analysis software ‘ANSYS’ is used in this analysis. Table 1 shows the description of the specimens.

RESULTS AND DISCUSSION

Finite element analysis was carried out to obtain the load carrying capacity of composite steel tubular column. The nonlinear analysis (large deformation static) was opted in ANSYS.

3.1 Effect Of Concrete Strength On The Composite Column:
The percentage decrease in the deflection of the composite column having slenderness ratio of 40 is about 6.9% for change in concrete strength from M15 to M25 and 4.7% for change in concrete strength from M25 to M35. The overall percentage decrease in the CFT column having slenderness ratio of 40 is about 11.3% for change in concrete strength from M15 to M25. Figure 12 shows the load-deflection for composite columns with the slenderness ratio of 40.

The percentage decrease in the deflection of the composite column having slenderness ratio of 50 is about 6.1% for change in concrete strength from M15 to M25 and 4.1% for change in concrete strength from M25 to M35. The overall percentage decrease in the CFT column having slenderness ratio of 50 is about 9.9% for change in concrete strength from M15 to M25. Figure 13 shows the load-deflection for composite columns with the slenderness ratio of 50.

The percentage decrease in the deflection of the composite column having slenderness ratio of 60 is about 5.9% for change in concrete strength from M15 to M25 and 4.2% for change in concrete strength from M25 to M35. The overall percentage decrease in the CFT column having slenderness ratio of 60 is about 9.8% for change in concrete strength from M15 to M25. Figure 14 shows the load-deflection for composite columns with the slenderness ratio of 60.

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Description</th>
<th>Length (mm)</th>
<th>Diameter (mm)</th>
<th>Thickness (mm)</th>
<th>Slenderness Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Column without In filled Concrete</td>
<td>800</td>
<td>60.3</td>
<td>3.2</td>
<td>40</td>
</tr>
<tr>
<td>2</td>
<td>Column with M15 Grade of Concrete</td>
<td>800</td>
<td>60.3</td>
<td>3.2</td>
<td>40</td>
</tr>
<tr>
<td>3</td>
<td>Column with M25 Grade of Concrete</td>
<td>800</td>
<td>60.3</td>
<td>3.2</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>Column with M35 Grade of Concrete</td>
<td>800</td>
<td>60.3</td>
<td>3.2</td>
<td>40</td>
</tr>
<tr>
<td>5</td>
<td>Column without In filled Concrete</td>
<td>1000</td>
<td>60.3</td>
<td>3.2</td>
<td>50</td>
</tr>
<tr>
<td>6</td>
<td>Column with M15 Grade of Concrete</td>
<td>1000</td>
<td>60.3</td>
<td>3.2</td>
<td>50</td>
</tr>
<tr>
<td>7</td>
<td>Column with M25 Grade of Concrete</td>
<td>1000</td>
<td>60.3</td>
<td>3.2</td>
<td>50</td>
</tr>
<tr>
<td>8</td>
<td>Column with M35 Grade of Concrete</td>
<td>1000</td>
<td>60.3</td>
<td>3.2</td>
<td>50</td>
</tr>
<tr>
<td>9</td>
<td>Column without In filled Concrete</td>
<td>1200</td>
<td>60.3</td>
<td>3.2</td>
<td>60</td>
</tr>
<tr>
<td>10</td>
<td>Column with M15 Grade of Concrete</td>
<td>1200</td>
<td>60.3</td>
<td>3.2</td>
<td>60</td>
</tr>
<tr>
<td>11</td>
<td>Column with M25 Grade of Concrete</td>
<td>1200</td>
<td>60.3</td>
<td>3.2</td>
<td>60</td>
</tr>
<tr>
<td>12</td>
<td>Column with M35 Grade of Concrete</td>
<td>1200</td>
<td>60.3</td>
<td>3.2</td>
<td>60</td>
</tr>
</tbody>
</table>
3.2 Effect Of Slenderness Ratio On The Composite Column:
The overall percentage decrease in the deflection of the composite column is about 38% for change in
slenderness ratio from 40 to 50. The decrease in deflection is about 3% for change in slenderness ratio from 50
to 60 and it is about 40% for change in slenderness ratio from 40 to 60 which is irrespective of the concrete
strength from M15 to M35. Figure 15 to 17 shows the load – Deflection curve of the composite column for the
M15, M25 and M35 grades of concrete. Figure 18 shows the load verses deflection behaviour of the hollow
section for varying slenderness ratio. Figure 19 and 20 shows the maximum deflection of the composite column
for varying slenderness ratio and concrete strength.

![Load - Deflection curve for Composite Columns of Slenderness Ratio 40](image1)

![Load - Deflection curve for Composite Columns of Slenderness Ratio 50](image2)

![Load - Deflection curve for Composite Columns of Slenderness Ratio 60](image3)

![Load - Deflection curve of Composite Columns for M15](image4)

![Load - Deflection curve of Composite Columns for M25](image5)

![Load - Deflection curve of Composite Columns for M35](image6)
Fig. 18: Load–Deflection curve of Hollow Columns for varying slenderness ratio

Fig. 19: Maximum deflection of composite column for varying slenderness ratio

Fig. 20: Maximum deflection of composite column for varying Grade of concrete

3.3 Strength Index (SI):

It compares the maximum load of the slender column within the resistance of the composite cross-section (confinement effect). It is similar to the buckling reduction factor (χ). For a member in axial compression without eccentricity from Eurocode 4, but it cannot be linked to any buckling curves. When the confinement index increases, the strength index also increases. Nevertheless, what it is noticeable is that the strength index (SI) does not seem to be greatly affected by the thickness of the section. Thus, table shows the strength index (SI) in terms of fck, 0 and λ for the experiments with a diameter D = 60.3 mm and t = 3.2mm. The strength index is defined as:

\[ Sl = \frac{N_{\text{max}}}{N_{\text{pl,Rd}}} = \frac{N_{\text{max}}}{A_{c}f_{ck} + A_{s}f_{y}} \]

Table 2 shows that with increase in relative slenderness (λ), there is decrease in Strength Index.

<table>
<thead>
<tr>
<th>SL.No</th>
<th>Specimens ID</th>
<th>Strength Index (SI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>HS</td>
<td>0.313</td>
</tr>
<tr>
<td>2</td>
<td>M15</td>
<td>0.247</td>
</tr>
<tr>
<td>3</td>
<td>M25</td>
<td>0.217</td>
</tr>
<tr>
<td>4</td>
<td>M35</td>
<td>0.193</td>
</tr>
</tbody>
</table>

Table 2: Strength Index of Various Slenderness Ratio

Figure 21 to 28 shows deformed shape, nodal solution, stress distribution and strain distribution of the tubular columns without infilled and filled concrete.
Fig. 21: Deformed shape of the Column without Infilled Concrete

Fig. 22: Nodal solution of the column without Infilled Concrete

Fig. 23: Von Mises stress of the Column without Infilled Concrete

Fig. 24: Von Mises strain of the Column without Infilled Concrete

Fig. 25: Deformed shape of composite column

Fig. 26: Nodal Solution of the composite column
Conclusion:
Based on the analytical study performed for all types infilled concrete, the following conclusions were made.

- The Strength Index (SI) decreases as the grade of the concrete increases.
- The enhancement of strength in the case of CFST columns depends on the compressive strength of filled concrete and on the confinement effect.

REFERENCES