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DEVELOPMENT OF AN APPROXIMATE FORMULA FOR ULTIMATE AXIAL LOAD CAPACITY OF RECTANGULAR CONCRETE FILLED STEEL TUBE SHORT COLUMNS USING FINITE ELEMENT ANALYSIS

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Abstract: Concrete-filled steel tubular (CFST) columns have become increasingly prevalent in building and bridge construction due to their hybrid nature. The steel tube provides formwork for the concrete, while the concrete prolongs local buckling of the steel tube wall and prevents excessive concrete spalling. Designing CFST columns poses challenges due to the lack of a proper formula for determining their axial load carrying capacity. This study aims to develop an approximate formula for the ultimate axial load carrying capacity of rectangular CFST short columns by establishing relationships between various material properties using a finite element model created in ANSYS software. The model's accuracy will be validated against experimental data obtained from the literature survey.

Keywords: *Concrete Filled Steel Tubes, Contact Elements, Contact Status, Finite Element Model, Short Column, Ultimate Axial Load*

1. Introduction

In a composite column, where a concrete-filled tube (CFT) member is employed, the integration of steel reinforcement within the concrete serves a critical role. This reinforcement provides vital confinement to the concrete, thereby augmenting the load-carrying capacity of the composite member. Functionally, the concrete filling within the steel hollow section not only mitigates the risk of local buckling in the steel but also enhances the ductility of the CFT member, extending its resilience up to the ultimate load. Through a symbiotic interaction between the steel and concrete, a composite column effectively resists external loading. This interaction is facilitated by mechanisms such as bond and friction, ensuring that both materials synergistically contribute to the structural integrity and performance of the composite column.

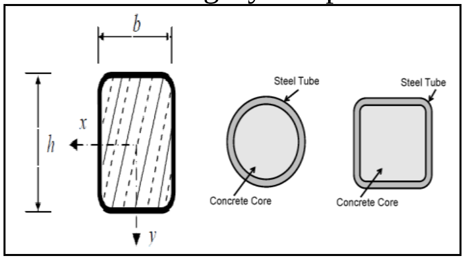


Figure 1 Typical cross sections of Concrete filled Steel Tubes

2. Finite Element Modeling

The finite element model of the Concrete filled Steel Tube (CFST) was constructed utilizing ANSYS 10.0 software. ANSYS is a commercially available Finite Element Method (FEM) package renowned for its versatility, offering capabilities spanning from straightforward linear static analyses to intricate nonlinear transient dynamic analyses. The finite element model was developed employing both Bottom Up and Top Down approaches through direct modeling techniques.

2.1 Description of the model

A Short Rectangular Plain Cement Concrete filled Steel tube (CFT) was modeled for the present study. The cross-section dimensions were set to 190 mm x 100 mm, with a length of 390 mm and a steel tube thickness of 4 mm. The concrete grade varied between 20 to 50 MPa, while the yield strength of the steel varied from 475 to 495 MPa. The Poisson’s ratio for steel was considered as 0.3.

To accurately simulate the composite action between the concrete and steel tube, friction-based normal contact was implemented. The inner surface of the stiffer steel tube acted as the rigid surface, while the outer surface of the concrete core served as the slave surface. A coefficient of friction of 0.25 was chosen to govern the interaction between these surfaces.

The study was further extended by considering a steel tube thickness of 5 mm. The boundary condition applied was fixed at the bottom of the specimen, with axial loading applied at the top of the column specimen.

2.2 Elements used to Model Concrete Filled Steel Tubes in ANSYS Software

SOLID65: The element described here is commonly utilized for three-dimensional modeling of solids, whether they contain reinforcing bars (rebars) or not. It is characterized by eight nodes, each possessing three degrees of freedom: translations along the nodal x, y, and z axes. This element is particularly suitable for modeling plain concrete infill within structures.

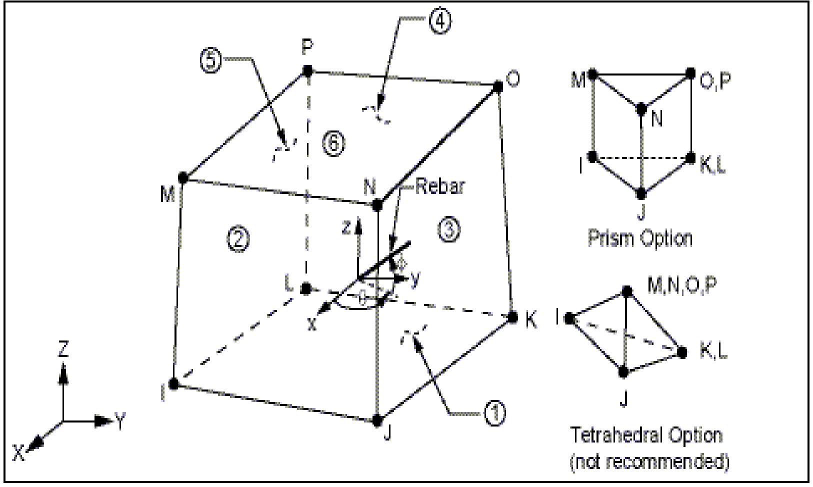


Figure 2 SOLID65 Geometry

SHELL63: The Shell 63 element is distinguished by its combined bending and membrane capabilities, allowing for the consideration of both in-plane and normal loads. At each node, the element boasts six degrees of freedom: translations along the nodal x, y, and z axes, as well as rotations about the nodal x, y, and z axes. This element is specifically employed for modeling steel tubes within structures.

Contact Elements: The interface between concrete and steel is modeled using contact elements. When two separate surfaces come into contact such that they become mutually tangent, they are considered to be in contact. In a physical sense, surfaces in contact exhibit the following characteristics: they do not interpenetrate; they can transmit compressive normal forces and tangential friction forces; they often do not transmit tensile normal forces, allowing them to separate and move away from each other. Contacts exhibit changing-status nonlinearity. For this purpose, CONTA 173 and TARGE 170 elements are employed. In this setup, the target surface represents the steel tube, while the contact surface represents the concrete infill. The contact surface moves into the target surface, mimicking the interaction between concrete and steel.

2.3 Modeling of the Specimen

The steel tube was constructed using the Bottom Up methodology, whereas the concrete infill was modeled employing the Top Down approach.

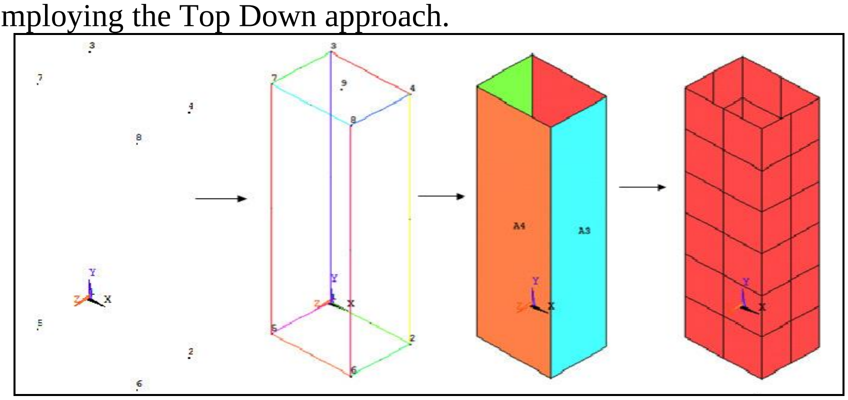


Figure 3 Completed Steel model

The model is finalized only after appropriately meshing both components. Both the steel tube and concrete infill are meshed to have identical sizes, facilitating easy contact between them. Contact pairs are established using the contact pair option, with the inner side of the steel tube designated as the target surface and the concrete infill as the contact surface. The contact between the concrete infill and steel tube is configured to maintain bonded contact with friction, ensuring that the gap between the steel tube and concrete infill remains closed and penetration into each other is prevented. Five types of contact status are available to establish the interaction between the steel tube and concrete infill: bonded, no separation, rough, frictional, and frictionless contact.

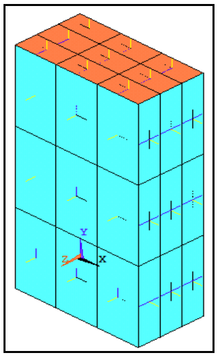


Figure 4 Model after applying contact pairs

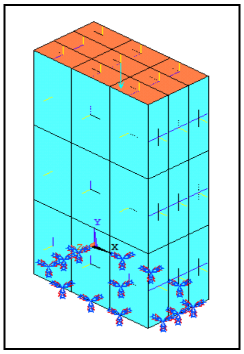


Figure 5 Completed model of column specimen

The model is then fixed at bottom side and an axial load is applied on the top of the short column specimen.

3. BUCKLING ANALYSIS

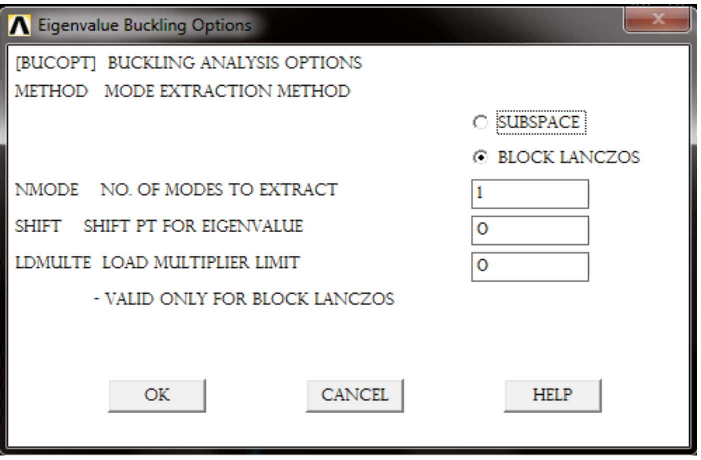
3.1 Buckling

Buckling represents a critical failure mode in structural mechanics, occurring when structures succumb to compressive loads. The strength of structures in buckling scenarios is contingent upon various factors such as support conditions, material properties (whether linear, composite, or nonlinear), and the presence of thermal loads or imperfections. Buckling behavior can manifest in stable, unstable, or neutral equilibrium states. Stability is observed when displacements increase gradually with rising loads, ensuring the structure's ability to withstand applied forces. Conversely, instability occurs when deformations escalate abruptly, leading to a rapid decline in load-bearing capacity and eventual structural collapse. Neutral equilibrium, though theoretical, involves deformation without a concurrent change in load. Buckling shares similarities with bending, both involving moments that induce bending. However, while bending moments in bending scenarios remain largely independent of resulting deflections, in buckling, moments and deflections are interdependent, causing stresses, moments, and deflections to deviate from proportional relationships with applied loads.

3.2 Types of Buckling Analysis

ANSYS supports two types of buckling analysis, namely linear buckling analysis and nonlinear buckling analysis. Both types of buckling analysis were conducted in the present study to ensure accurate results.

Eigen Value Buckling Analysis: Eigenvalue buckling analysis anticipates the theoretical buckling strength, known as the bifurcation point, of an ideal linear elastic structure. This approach mirrors the traditional method of elastic buckling analysis found in textbooks. For instance, performing an eigenvalue buckling analysis on a column aligns with the classical Euler solution. However, imperfections and nonlinearities present in most real-world structures prevent them from reaching their theoretical elastic buckling strength. Consequently, eigenvalue buckling analysis frequently produces overly optimistic outcomes and is typically unsuitable for practical engineering assessments.



Eigenvalue Buckling Options

[BUCOPT] BUCKLING ANALYSIS OPTIONS

METHOD MODE EXTRACTION METHOD
○ SUBSPACE
● BLOCK LANCZOS

NMODE NO. OF MODES TO EXTRACT 1

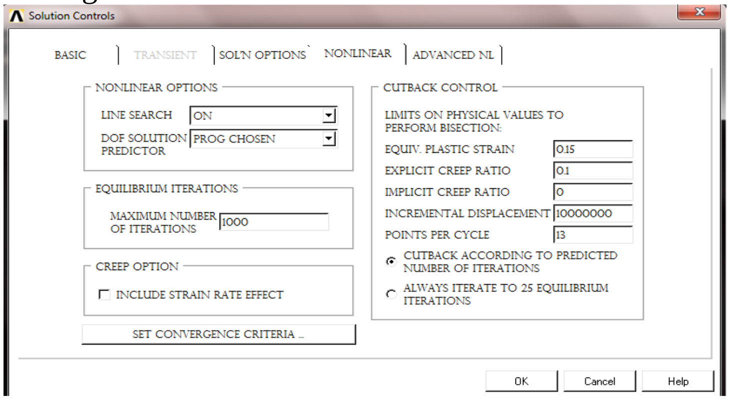
SHIFT SHIFT PT FOR EIGENVALUE 0

LDMULTE LOAD MULTIPLIER LIMIT 0

- VALID ONLY FOR BLOCK LANCZOS

Figure 6 Table of Eigen Buckling Analysis

Non-Linear Buckling Analysis: Nonlinear buckling analysis is typically more precise and is preferred for designing or assessing real structures. This method utilizes a nonlinear static analysis with incrementally increasing loads to determine the load level at which the structure becomes unstable. By employing the nonlinear approach, the model can encompass characteristics such as initial imperfections, plastic behavior, gaps, and significant deflection response. Furthermore, with deflection-controlled loading, it becomes possible to monitor the post-buckled behavior of the structure, which can be valuable in instances where the structure buckles into a stable configuration.



NONLINEAR OPTIONS
LINE SEARCH: ON
DOF SOLUTION PREDICTOR: PROG CHOSEN

EQUILIBRIUM ITERATIONS
MAXIMUM NUMBER OF ITERATIONS: 1000

CREEP OPTION
☐ INCLUDE STRAIN RATE EFFECT

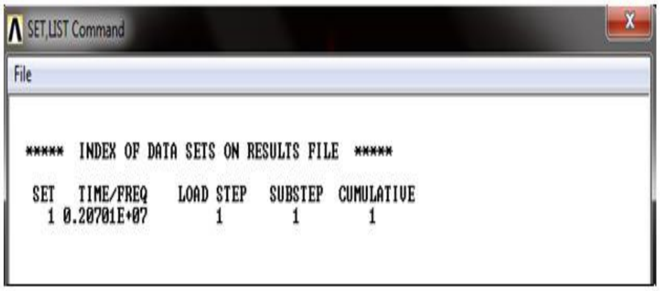
CUTBACK CONTROL
LIMITS ON PHYSICAL VALUES TO PERFORM BISECTION:
EQUIV. PLASTIC STRAIN: 0.15
EXPLICIT CREEP RATIO: 0.1
IMPLICIT CREEP RATIO: 0
INCREMENTAL DISPLACEMENT: 10000000
POINTS PER CYCLE: 13
● CUTBACK ACCORDING TO PREDICTED NUMBER OF ITERATIONS
○ ALWAYS ITERATE TO 25 EQUILIBRIUM ITERATIONS

Figure 7 Table of solution controls for Non Linear Analysis

4. Result Obtained from ANSYS

The aim of carrying out both the types of buckling analysis was to have a more accurate result for obtaining the relation between material and geometric properties so that new equation going to be developed becomes reasonable with the obtained experimental results values. The obtained relations are plotted in graphs as shown in Figure (9) and Figure (10). It is observed that both Eigen Value Buckling Analysis and Non linear buckling analysis (time history output) output for a sample model specimen A-14-1 (Table 1).

The objective of conducting both types of buckling analyses was to achieve greater accuracy in establishing the relationship between material and geometric properties, ensuring that the forthcoming equation, based on the obtained experimental results, is justified. The derived relationships are illustrated in graphs depicted in Figure (9) and Figure (10). It is noted that both Eigenvalue Buckling Analysis and Nonlinear Buckling Analysis (time history output) were conducted for a representative model specimen A-14-1 (Table 1).



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 *****  INDEX OF DATA SETS ON RESULTS FILE  *****

  SET   TIME/FREQ    LOAD STEP   SUBSTEP  CUMULATIVE
    1 0.20701E+07        1          1         1
```

Figure 8 Detailed Summary of Eigen buckling analysis for A-14-1

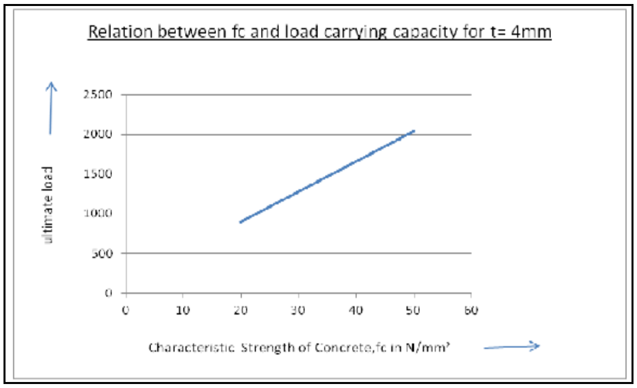

Figure 9 Relation between ultimate load and fc for t = 4 mm

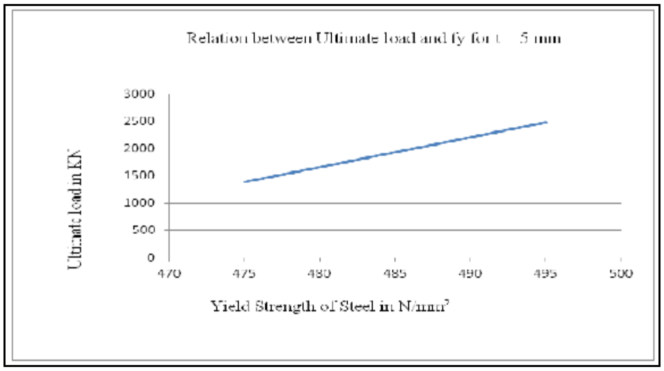

Figure 10 Relation between ultimate load and Yield strength of steel for thickness of steel tube, t = 4 mm

5. Comparison of Results

To furnish the requisite experimental data for validating my thesis, I gathered data from experiments conducted by Schneider in 1998, Han in 2002, Liu et al. in 2003 and 2004, as documented in the journal titled 'Numerical Modeling of Rectangular Concrete-Filled Steel Tubular Short Columns' authored by Heaven Singh and P.K. Gupta in the International Journal of Scientific and Engineering Research.

Table 1 Details of Experimental Data

Specimen label	B	H	T	B/H	B/t	L	fc	fy	Es	Exp. Peak Axial load
	mm	mm	mm			mm	MPa	MPa	GPa	kN
R2	152.8	76.5	4.47	2	34.18	611	26.04	383	213.59	1006
R5	151.4	101.3	5.72	1.5	26.47	606	23.80	324	204.63	1335
A-14-1	190	100	4.0	1.9	47.50	390	55	495	206	2038

Table 2 Comparison of Ultimate Load obtained in ANSYS 10.0 with Experimental Data

Sl.NO:	Experimental Data (kN)	ANSYS Output (kN)
A-14-1	2038	2070

Table 3 Comparison of Ultimate Load obtained in New Formula with Experimental Data

Sl.NO:	Experimental Data (kN)	Result obtained using new formula(kN)
A-14-1	2038	2001
R2	1006	1118
R5	1335	1342

Observations from Table 2 and Table 3 indicate that the newly derived formula for determining the ultimate load-carrying capacity of CFST tubes demonstrates favorable alignment with the corresponding experimental data. Thus, this formula holds promise for application in short CFST columns featuring rectangular cross-sections, albeit within certain limitations.

6. Conclusion

In recent times, the utilization of Concrete Filled Steel Tubes (CFST) in the construction sector has been steadily increasing, particularly in foreign nations. However, in India, the adoption of CFST is somewhat hindered due to the absence of specific provisions in our national building codes. The existing Indian Standard Codes primarily cater to Reinforced Concrete Columns, leaving a gap in guidelines for CFST applications. To address this gap, an endeavor has been made to formulate a new equation for determining the ultimate load-carrying capacity of short CFST columns. This effort draws on insights gained from finite element modeling conducted using ANSYS 10.0 software. Through this modeling approach, a new equation has been derived by incorporating additional constants into the basic load-area relationships. Remarkably, the resulting formula demonstrates notable agreement with available experimental data. Although the derived equation pertains to short theoretical columns, its successful formulation suggests promising prospects for future research endeavors in this area. This achievement serves as a catalyst for further exploration aimed at developing formulas applicable to real-world structural scenarios.

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