BUCKLING BEHAVIOR OF CONCRETE FILLED STEEL TUBE UNDER FINITE ELEMENT METHOD

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ABSTRACT:

This study focuses on the behavior of concrete-filled tubular (CFST) columns under axial load and. The study was conducted using ANSYS finite element software. Slender columns were studied with varying slenderness ratio (31.58-125). Analysis was run for both hollow tubes and CFST. Results were compared to study buckling failure modes and section capacities. The results showed that global buckling governed for the slender columns. Comparison of hollow and CFST tubes showed that the concrete core delayed the onset of local buckling of the steel tube.

Keywords: BUCKLING, ANSYS, FEM, CFST, HOLLOW TUBE

1.0 INTRODUCTION:

When a column (subjected usually to compression) undergoes visibly large displacements transverse to the load then it is said to buckle. Buckling is a critical phenomenon in structural failure. Buckling is the failure of structures under compression load. Also buckling strength of structures depends on many parameters like supports, linear materials, composite or nonlinear material etc. Also buckling behavior is influenced by thermal loads and imperfections.

Analyzing all these conditions is difficult task. So few parameters are considered for the present work. CFST columns have the potential of becoming common place structural members in both low-rise and high-rise building construction. The advantages of using CFT columns in structures are: economic designs, improved constructability, and enhanced performance. CFST columns are constructed by erecting hollow steel columns as a structure's frame which is then filled with concrete as construction advances. The use of CFT columns in construction offers several major economic advantages over steel or reinforced concrete columns; since the steel tube serves as formwork and confinement for the concrete, the material and labor costs associated with formwork and steel reinforcement are eliminated. CFTs also allow steelwork to precede several stories above concrete pouring, which reduces construction time and improves the coordination of steel and concrete trades. The composite action of steel and concrete is what gives CFT columns their advantages over standard steel or reinforced concrete columns. The concrete core can act to increase the stiffness and compressive strength of the hollow steel tube and to delay local buckling. The hollow steel tube acts as concrete reinforcement, resists bending moments and shear forces, and confines the concrete thereby increasing ductility. These potential benefits of composite action depend largely on the bond at the steel-concrete interface. Unfortunately the transfer of stress through the interface bond is not well understood. The use of these systems and the development of design guidelines are hampered by a lack this lack of information.

2.0 FINITE ELEMENT METHODS:

2.1 INTROUDUCTION:

The basic concept of finite element method is discritization of a structure into finite number of elements, connected at finite number of points called nodes. The material properties and the governing relationships are considered over these elements and expressed in terms of nodal displacement at nodes.An assembly process duly considering the loading and constraints results in a set of equations governing the structural response, which are established through the application of appropriate variation principle. Solutions of these equations give the response of the structure. Selecting proper elements and subdividing the structure with large number of finite elements or by taking higher order elements can increase the accuracy of solution obtained by finite element method. In modern design practice, with the advent of large and fast modern digital computers and advancement in numerical techniques; solutions to various static and dynamic problems has become fast and efficient.

2.2 MERITS OF FINITE ELEMENT METHOD:

The systematic generality of finite element procedure makes it a powerful and versatile tool for a wide range of problems. Thus, flexible, general-purpose computer programs can be developed and can be applied to various problems with little or no modification. FEM can be easily interpreted in physical terms. As well it has a strong mathematical base. Hence, finite element method can be easily applied to any problem with a proper knowledge of the physical system under consideration and can be solved to a greater accuracy by the application of proper mathematical tool. Non-homogenous continuum can also be dealt with by merely assigning different properties to different elements. It is even possible to vary the properties within an element according to the polynomial applied. Finite element method accommodates complex geometry with ease and is capable of handling non-linear and time dependent system also. In finite element method, since boundary conditions are introduced in the assembled equations, it requires only to specify the geometric boundary conditions without regarding its effects on interior elements. Since the boundary conditions do not enter into the individual finite element equations, the field variable models need not be changed, when the boundary conditions change. Finite element method considers the multidimensional continuity of body. Hence it does not require separate interpolation process to extend the approximate solution to every point within the continuum. It does not also require the trial solutions that must all apply to the entire multidimensional continuum.

2.3 DEMERITS OF FINITE ELEMENT METHOD:

The solution obtained from FEM can be realistic if and only if the material properties are known precisely. The major drawback of FEM is sensitivity of the solution on the geometry of the element such as type, size, number, shape and orientation of elements used. The computer programs of FEM require relatively a large computer memory and time. FEM Programs yield a large amount of data as results.

3.0 ANSYS:

ANSYS is a commercial FEM package having the capabilities ranging from a simple, linear, static analysis to a complex, nonlinear, transient dynamic analysis. It is available in modules. Each module is applicable to specific problem. For example, Ansys/Civil is applicable to civil structural analysis. Similarly Ansys/Flotran is CFD software applicable to Fluid Flow. The advantage of Ansys compared to other competitive software's is , its availability as bundled software of pre, post and a Processor. Typical Ansys program includes 3 stages.

- Pre-Processing
- Solution
- Post-Processing

3.1 MODELING

This is the important step of creating the physical object in the system. They are two types of modeling in Ansys. Direct Modeling & Solid Modeling

a) **DIRECT MODELING:** In this approach the physical structure is represented by nodes and elements directly. The problem is solved once after the boundary conditions are applied. This approach is simple and straight forward. Takes very little time computation. But this can be applied only for simple problems. When problem becomes complex, this method becomes tedious to apply.

b) **SOLID MODELING:** Models are directly created either using Ansys Preprocessor or imported from popular CAD soft ware's like Mechanical Desktop, Pro/E, CATIA, SOLID WORKS etc. Once the structural model is created, by using mesh tool, the model can be meshed and problem can be solved by applying the boundary conditions.

3.2 ELEMENTS:

3.2.1 SHELL181:

SHELL181 is suitable for analyzing thin to moderately-thick shell structures. It is a four-node element with six degrees of freedom at each node: translations in the x, y, and z directions, and rotations about the x, y, and z-axes. The element SHELL181 was used to model the steel tube. All specimens were modeled as 3D structural elements.

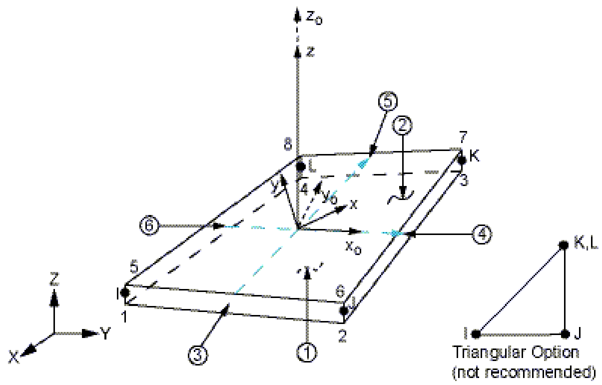

Figure 1: SHELL 181 GEOMETRY

3.2.2 CONCRETE 65

The element SOLID 65 was used to model the concrete core of the columns. SOLID 65 supports the cracking in tension and crushing in compression properties of concrete. The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions.

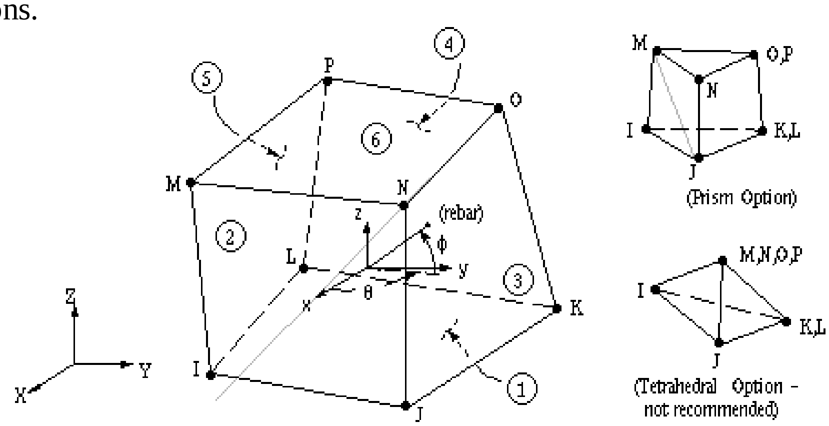

Figure 2: SOLID 65 GEOMETRY

4.0 THEORETICAL BUCKLING ANALYSIS

Steel tube or columns are usually thought of as straight vertical members whose lengths are considerably greater than their cross-sectional dimensions. An initially straight tube or column, compressed by gradually increasing equal and opposite axial forces at the ends is considered first. When the applied loading is increased, the buckling deformation also increases. Buckling occurs mainly in members subjected to compressive forces. If the member has high bending stiffness, its buckling resistance is high. Also, when the member length is increased, the buckling resistance is decreased.

4.1 BUCKLING OF AN IDEAL COLUMN OR TUBE

The classical Euler analysis of this problem makes the following assumptions.

- The material of which the strut is made is homogeneous and linearly elastic (i.e. it obeys Hooke's Law).

- The column is perfectly straight and there are no imperfections.
- The loading is applied at the centroid of the cross section at the ends.

4.2 EULER FORMULA:

$$P_{cr}=\frac{\pi^2 EI}{L_e^2}$$

Using buckling value of FEM model was verified with the theoretical Euler critical buckling load formula.

5.0 ANSYS EIGEN VALUE BUCKLING:

Eigen value buckling analysis predicts the theoretical buckling strength (the bifurcation point) of an ideal linear elastic structure. This method corresponds to the textbook approach to elastic buckling analysis: for instance, an Eigen value buckling analysis of a column will match the classical Euler solution. However, imperfections and nonlinearities prevent most real-world structures from achieving their theoretical elastic buckling strength. Thus, Eigen value buckling analysis often yields un conservative results, and should generally not be used in actual day-to-day engineering analyses.

Procedure for Eigenvalue Buckling Analysis
Eigenvalue buckling analysis generally yields un conservative results, and should usually not be used for design of actual structures. The procedure of eigenvalue buckling analysis is as follows.

- Building the model.
- Obtaining the static solution.
- Obtaining the eigenvalue buckling solution.
- Expanding the solution.
- Reviewing the results

5.1 BUILDING THE MODEL

The Model is built is either through Bottom up Approach or Top down Approach and should be meshed with appropriate elements. Proper material and geometric properties (Real properties) should be supplied. Finally Boundary conditions should be supplied.

5.2 OBTAINING THE SOLUTION

The following should be followed to obtain proper solution Prestress effects [PSTRES] must be activated. Eigenvalue buckling analysis requires the stress stiffness matrix to be calculated. Unit loads are usually sufficient (that is, actual load values need not be specified). The eigenvalues calculated by the buckling analysis represent buckling load factors. Therefore, if a unit load is specified, the load factors represent the buckling loads. All loads are scaled. Eigenvalues represent scaling factors for all loads. If certain loads are constant (for example, self-weight gravity loads) while other loads are variable (for example, externally applied loads), we need to ensure that the stress stiffness matrix from the constant loads is not factored by the eigenvalue solution. One strategy that we can use to achieve this end is to iterate on the eigen solution, adjusting the variable loads until the eigenvalue becomes 1.0 (or nearly 1.0, within some convergence tolerance). Design optimization could be useful in driving this iterative procedure to a final answer.

5.3 OBTAINING THE EIGEN VALUE BUCKLING SOLUTION:

After executing the program for static solution, again solution should be changed to Eigen Buckling and extraction technique should be specified.

5.4 EXPANDING THE SOLUTION:

Solution should be expanded to obtain the critical buckling loads.

5.5 REVIEWING THE RESULTS:

Results can be reviewed through post1. Through result summary critical buckling in the form of natural frequencies can be viewed. By using the read set option for different critical loads, deflection and stress patterns can be viewed.

5.6 ASSUMPTIONS

- The Member is initially perfectly straight and is axially loaded.
- The material is Elasto-plastic with strain hardening materials.
- The self weight of the structure is not considered
- The member will fail by buckling alone.
  Imperfections of members are not considered.

6.0 MATERIAL SPECIFICATION:

STEEL

- Material : Structural Steel Fe 250Mpa
- Young’s Modulus E=200Gpa
- Poison’s ratio v=0.3
- Density p=7800kg/m3.

CONCRETE

- Grade of Concrete: M25
- Young’s Modulus E=25000Mpa
- Poison’s ratio v=0.16
- Density p=2400kg/m3

7.0 BOUNDARY CONDITIONS:

For each of the two ends, two different types of boundary conditions (Figure.4) were used. At the bottom end fixed, displacement degrees of freedom in 1, 2, 3 directions (U1, U2, U3) as well as rotational degrees of freedom in 1, 2, 3 directions were restrained to be zero. At the top end is roller support movable end rotational degrees of freedom are free and translation U2 is free remaining U1, U2 are restrained.

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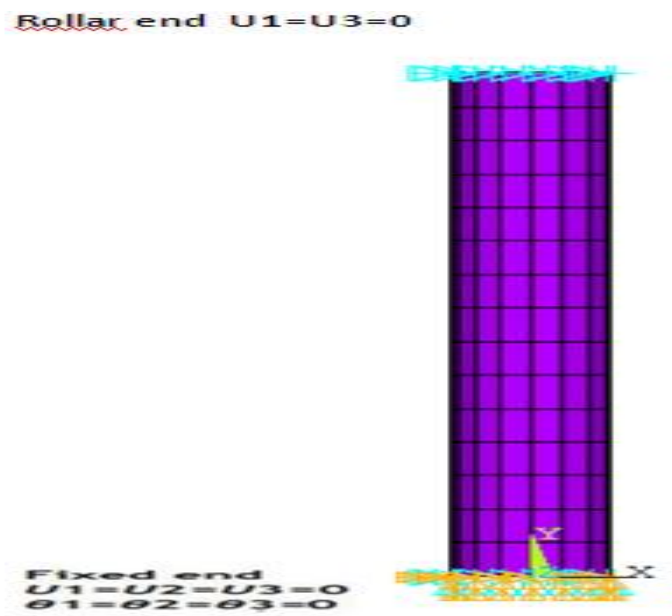


Figure 3: BOUNDARY CONDITION

8.0 SPECIMEN GEOMETRY:

All modeling was conducted using ANSYS 13 finite element software. The project proceeded in several stages of modeling; hollow specimens were modeled as 3D shell181 and concrete specimens were modeled as solid65 element with identical geometry. The dimensions of the sections were chosen to match those being used in the experimental testing of the deportment thesis project. A total of 30 specimens were analysis for this study. 15 models were developed for hollow tube section and another 15 models for CFT section both specimen's diameter and thickness varying. Figure 1 and 2 shows the geometry of the sections modeled

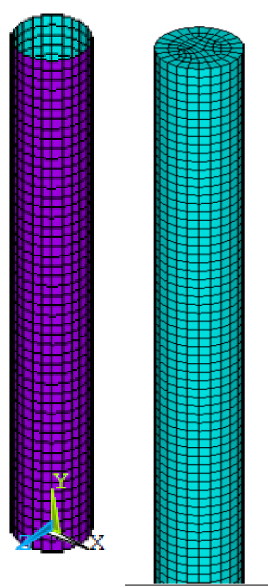


Fig.4: Hollow Steel Tube & Concrete Filled

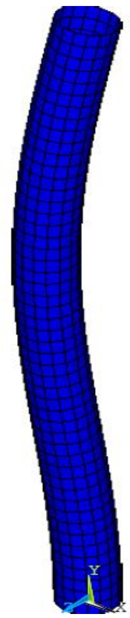


Fig.5: Global Buckling Of Hollow Tube

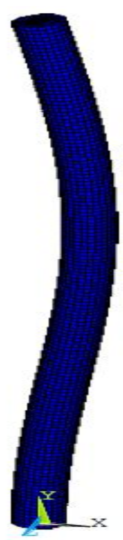


Fig. 6: Global Buckling of Concrete Filled Steel Tube

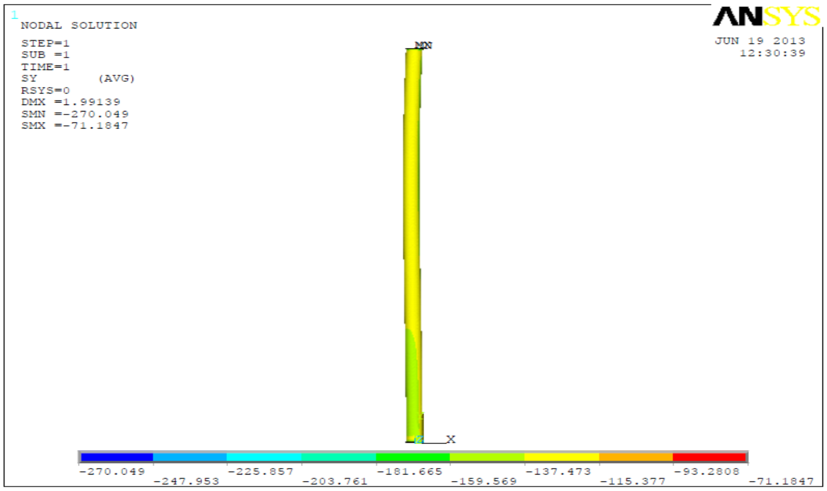


Fig.7: **Buckling Stress for Hollow Tube**

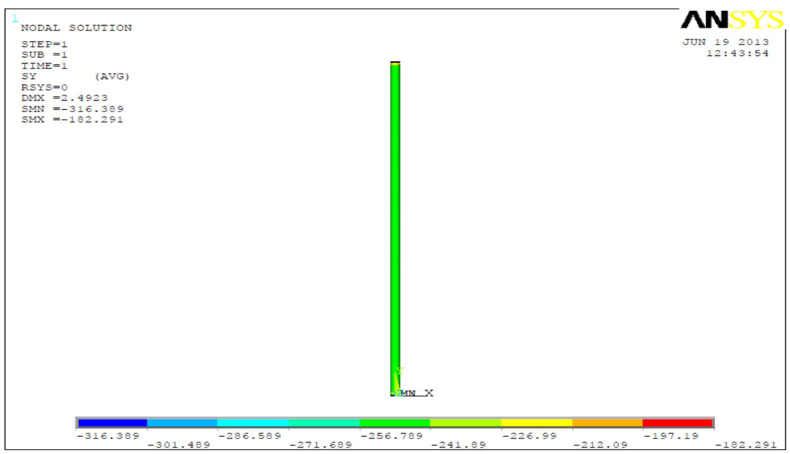


Fig.8: **Buckling Stress for CFST**

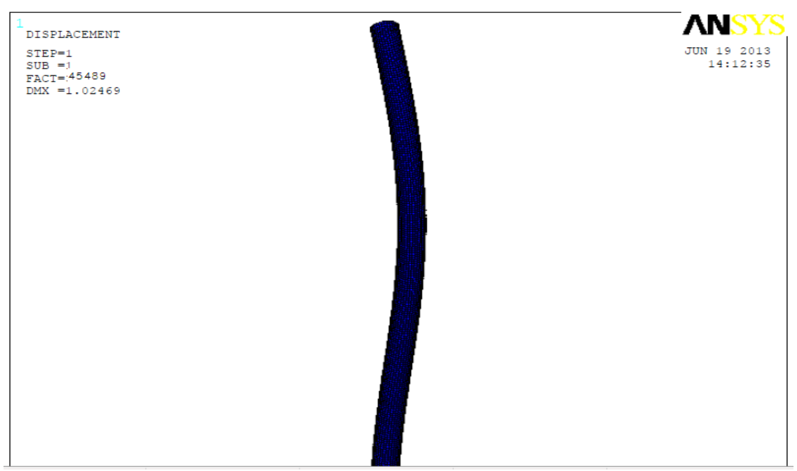


Fig.9: **Buckling of Hollow Tube**

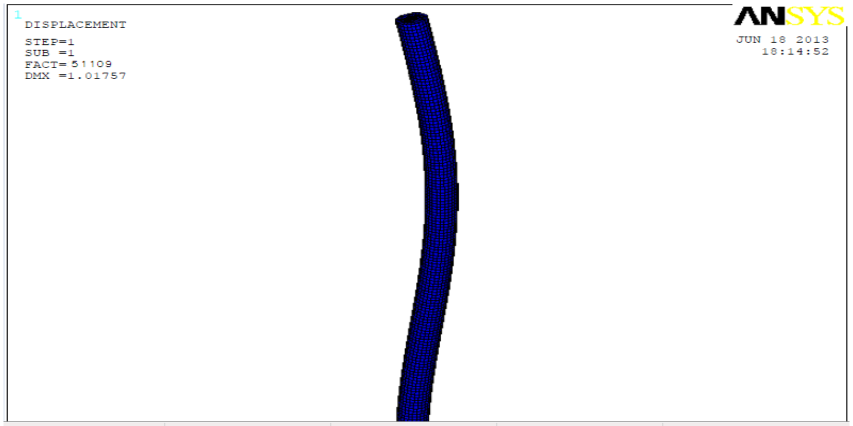


Fig.10: Buckling of CFT

Table.1: MECHANICAL BUCKLING OF HOLLW STEEL TUBE RESULTS

Sl. no	Seri-es	Diameter (mm)	Thickness (mm)	Slenderness ratio	Buckling Load FEM (KN)	Buckling Load THEORETICAL (KN)	FEM / Theoretical	MIN Vertical Buckling Stress (Mpa)	MAX vertical Buckling Stress (Mpa)
1	1	42.4	2.9	45	342	350.93	0.974553	716.93	1186.83
2				60	194.39	197.20	0.985751	375.56	632.00
3				75	124.53	126.33	0.985752	240.56	405.78
4				100	70.27	71.065	0.988813	142.03	222.45
5				125	45.48	44.80	1.015179	81.75	120.65
6	2	48.3	3.7	39.82	626	645.00	0.970543	883.91	1534.15
7				53.82	356.29	363.09	0.981272	503.38	873.68
8				66.37	228.58	232.37	0.98369	322.22	559.44
9				88.49	129.10	130.71	0.987683	182.29	316.38
10				110.61	83.65	82.46	1.014431	118.11	205.00
11	3	60.3	4.0	31.58	1342.7	1401.13	0.958298	1335.57	2462.42
12				42.10	767.12	788.13	0.973342	763.55	1407.88
13				52.71	494.96	504.40	0.981285	492.55	907.77
14				70.28	280.20	283.73	0.987559	278.79	513.89
15				87.71	181.58	180.20	1.007658	180.68	333.02

Table.2: **MECHANICAL BUCKLING OF CONCRETE FILLED STEEL TUBE RESULTS**

Sl. no	Ser -ies	Diameter (mm)	Thickness (mm)	Slenderness ratio	Buckling Load FEM (KN)	Buckling Load THEORE-TICAL (KN)	FEM / Theoretical	MIN Vertical Buckling Stress (Mpa)	MAX vertical Buckling Stress (Mpa)
1	1	42.4	2.9	59.43	385.5	383.69	1.004848	192.05	555.09
2				79.24	214.4	215.82	0.995459	89.52	299.03
3				99.05	138.4	138.12	1.005213	56.04	151.06
4				132.07	77.81	77.71	1.001287	25.89	135.11
5				165.07	50.10	49.80	1.006024	20.70	85.02
6	2	48.3	3.7	52.19	688.7	696.52	0.989017	197.04	747.49
7				69.59	394.3	391.79	1.007249	112.87	427.81
8				86.99	248.8	250.75	0.991745	71.81	270.04
9				115.99	143.3	141.04	1.014818	41.02	155.67
10				144.98	90.16	90.29	0.99856	28.34	109.84
11	3	60.3	4.0	41.80	1511.7	1538.00	0.9829	281.18	942.31
12				55.73	856.0	865.12	0.989458	159.21	533.58
13				69.67	550.8	553.68	0.99404	102.45	343.44
14				92.89	314.1	311.44	1.008894	58.13	195.79
15				116.12	198.5	199.32	0.998144	36.92	123.72

DIAMETER & WALL THICKNESS OF ALL SPECIMEN

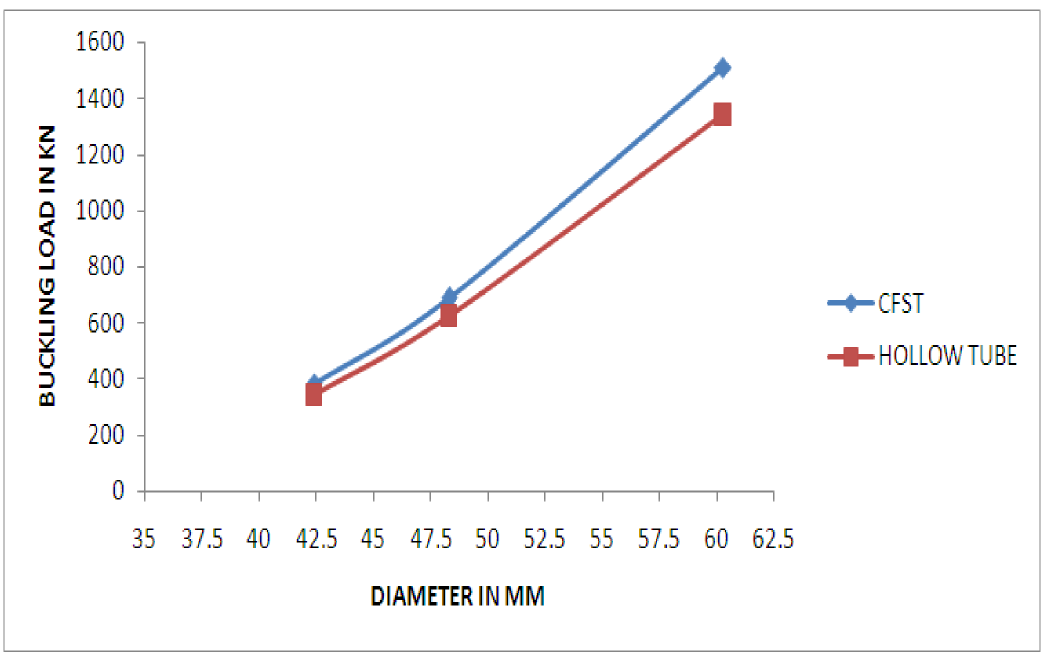


Fig.11: Diameter v/s Buckling Load

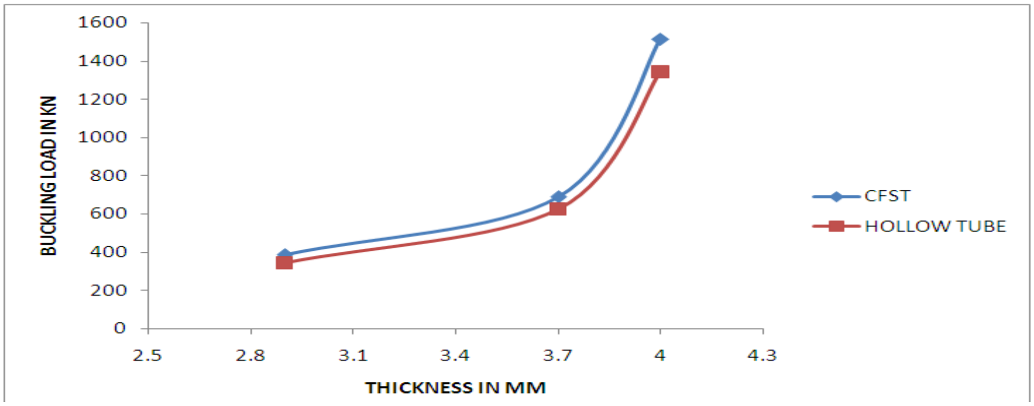


Fig.12: Thickness v/s Buckling Load

Series -1 specimen

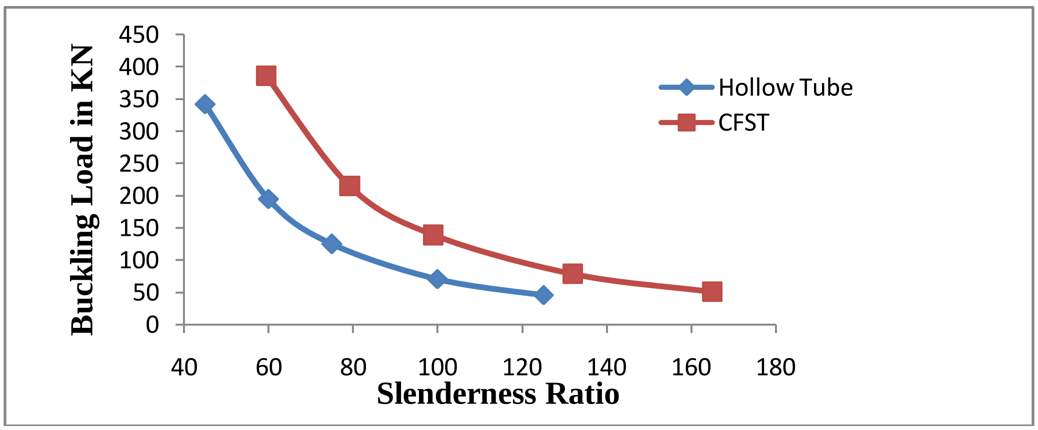


Fig.13: Slenderness Ratio v/s Buckling load

Series-2 Specimens

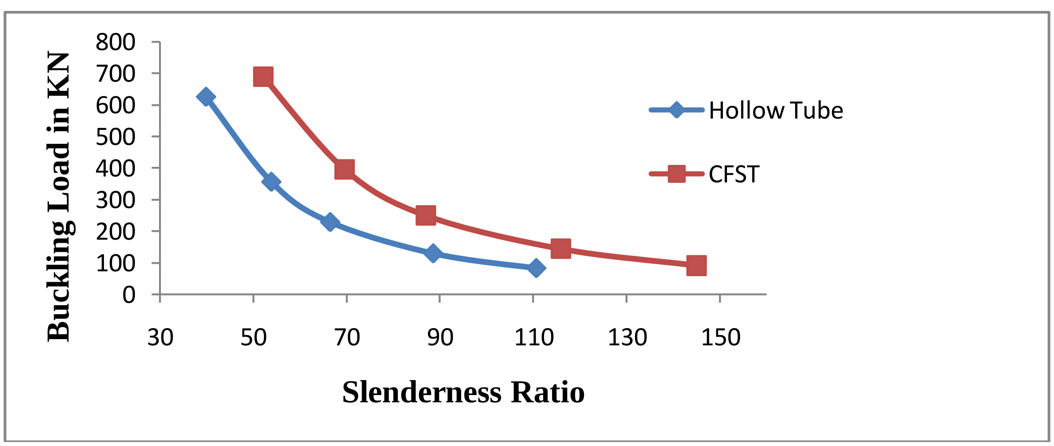


Fig.14: Slenderness Ratio v/s Buckling Load

Series -3 SPECIMENS

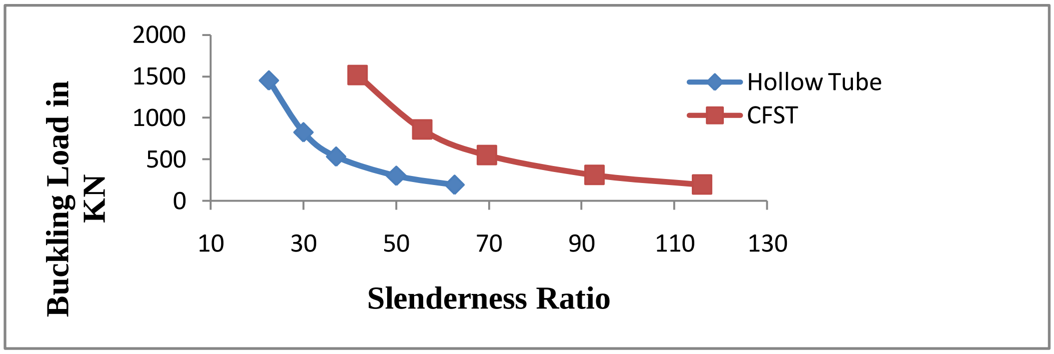


Fig.15: Slenderness Ratio v/s Buckling Load

Series -1 Specimen

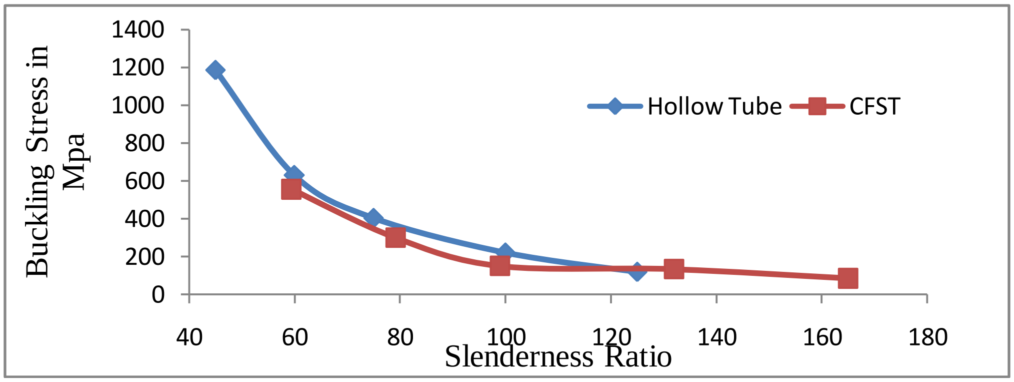


Fig.15: Slenderness Ratio v/s Buckling Stress

Series-2 Specimen

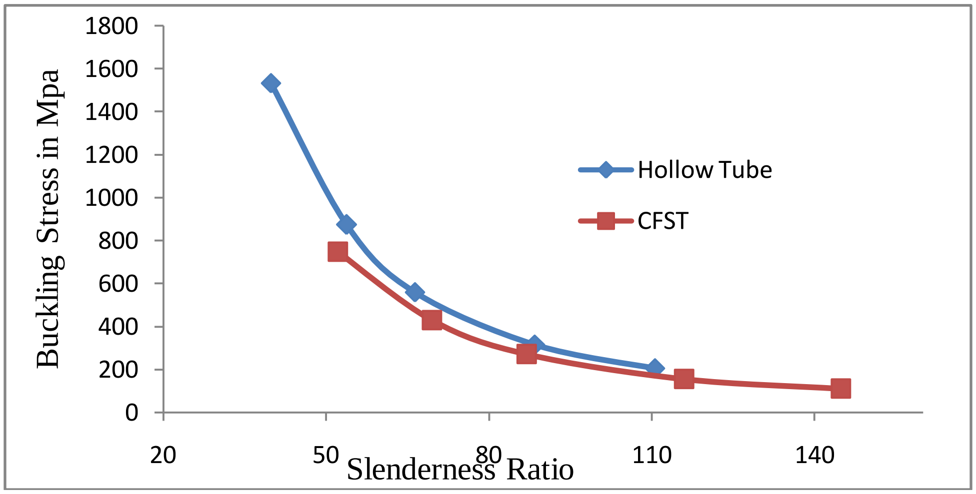
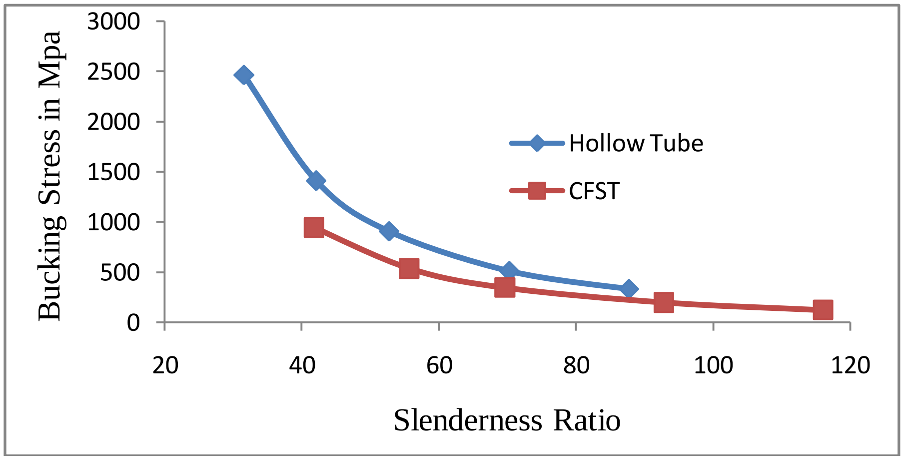


Fig.16: Slenderness Ratio v/s Buckling Stress



Series -3 specimen

Fig.17: Slenderness Ratio v/s Buckling Stress

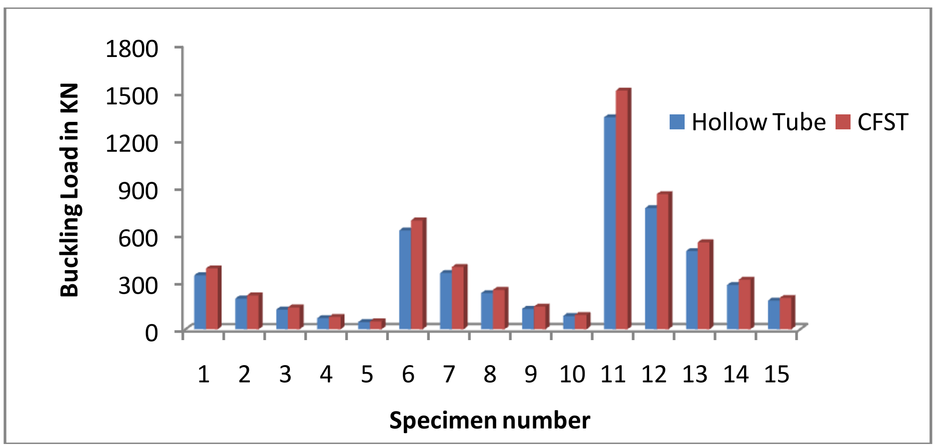


Fig.18: Specimen number v/s Buckling load

10.0 RESULTS & DISCUSSION:

Eigen buckling analysis is carried out for the Hollow Steel Tube and CFST structures to find actual buckling capacity of the structures. Comparative study is carried out between buckling load, buckling stress of Hollow Steel Tube and CFST members. The Fig.8 shows a buckling maximum stress for CFT around 270.04MPa due to elastic buckling. Since material property is assumed as linear, the stress levels are crossing the yield limits.Fig.7 shows a buckling maximum stress for Hollow Steel Tube around 316.38Mpa due to elastic buckling. stress levels crossing the yield limits. The fig:9 shows a buckling mode shape for Hollow steel Tube around 45.48KN slenderness ratio is 125.fig:10 shows a buckling mode shape for CFST around 50.10KN slenderness ratio is 125 In this analysis low slenderness ratio specimen getting high buckling load and high slenderness ratio specimen getting low buckling load. Table 1 and 2 shows all specimens' results.

10.1 DISCUSSION:

Buckling is main problem with many columns, reactor vessels, pipe lines, storage vessels etc. This buckling may be due to compressive loads created due to self weight or outer members or internal pressure or may imperfections in the system. But structural failure creates huge loss to the inventory of company and also life of the system. So proper check need to be done for buckling of t components. In the present work, Hollow Steel Tube and CFST geometries are analyzed for buckling loads. Initially the geometry is built using ANSYS preprocessor. Inspection of the results shows that all specimen failed due to global buckling carry the expected load predicted by theory. Figure 3 and 4 plots the results for the Hollow Tube and CFT specimens respectively. The graph shows that the greatest thickness and diameter of specimen buckling capacity is high and high slender ratio columns carried less percentage of load than the low slenderness ratio columns these results shown that the hollow tube and CFT models. The results also show closeness of Theoretical and Analytical buckling loads.

11.0 CONCLUSIONS

A Finite element analysis is carried out to find buckling strength of Hollow Steel Tube and CFST structures. Hollow Steel Tube and CFST members are mainly used in columns of multistory structures, bridge piers, earthquake resisting structure and other industrial applications. The results summary is as follows.

- Initially both Hollow Tube and CFST geometries are built
  .
- Buckling analysis is carried out in both Hollow Tube and CFST domain
- The stresses are very high in the small slenderness ratio of Hollow Tube region and for nonlinear analysis the stresses are very less in the high slenderness ratio of CFST.
- The results show the Hollow Tube buckling load carrying capacity less compared to the CFST buckling loads.
- Initially both theoretical and analysis values are compared to check Finite element solution with theoretical calculations. Also graphical plots are represented to find effect of thickness, diameter, and slenderness ratio on stress and buckling strength estimates.

12.0 Nomenclature

E Young's Modulus

I Moment inertia

L_e Effective Length

mm mili meter

KN Kilo Newton

Mpa Mega pascal

CFST Concrete Filled Steel Tube

References

[1]. Banks, W. M, and Rhodes, J., (1983) The Instability of Composite Sections, 2nd Int. Conf. On Composite Structures, Paisley, UK, Elsevier, 442-452.

[2]. Barbero, E. J., and Raftoyiannis, I. (1990) Buckling Analysis of Pultruded Composite Columns, Impact and Buckling of Structures, Ed. D. Hui, ASME AD-Vol. 20, AMD-Vol. 114, 47-52.

[3]. Barbero, E. J. and J. Tomblin, (1994) A Phenomenological Design Equation for FRP Columns with Interaction Between Local and Global Buckling, Thin-Walled Structures, 18, 117-131.

[4] 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.

[5] Commentary to the Third Edition of the Design Manual for Structural Stainless Steel,downloadablefromwww.steelstainless.org/designmanual.

[6] Gardner L. The use of stainless steel in structures. Progress in Structural Engineering and Materials 2005;7(2):45–55.

[7] ACI 318. Building code requirements for structural concrete. Detroit: American Concrete Institute; 1995.

[8] EN 1994-1-1, Eurocode 4: Design of composite steel and concrete structures, Part 1-1: General rules and rules for buildings. CEN, 2004.

[9] Sakino K, Tomii M, Watanabe K. Sustaining load capacity of plain concrete stub columns by circular steel tubes. In: Conference on concrete filled steel tubular construction; 1998, p. 112–18.

[10] Gardner L. The use of stainless steel instructures. Progress in Structural Engineering and Materials 2005;7(2):45–55.

[11]GardnerL.Thecontinuousstrengthmethod.ProceedingsoftheInstitutionofCivilEngineers-StructuresandBuildings [submittedforpublication].

[12] Packer JA, Henderson JE. Hollow structural section connections and trusses—Adesign guide. Toronto, Canada: Canadian Institute of Steel Construction (CISC); 2003.

[13] Gardner L, Cruise RB, Sok CP, Krishnan K, Ministro dos Santos J. Life cyclecosting of metallic structures. Proceedings of the Institution of Civil Engineers — Engineering

Sustainability 2007;60(4):166–77.

[14] Strength of Materials – S.S. Bhavikatti

[15] Strength of Materials – S.Ramamrutham [15] Conrete filled steel tubular columns, a finite element study- By Aaron W. Malone University of Massachusetts Amherst Department of Civil and Environmental Engineering 236 Marston Hall ,Amherst, MA 10003 (413) 577-0142