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Finite Element Analysis of Concrete Filled Steel Tube (CFT's) Subjected to Flexure

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Abstract: *This paper presents a study on flexural behaviour of concrete filled steel tube based on the former work carried out by Manojkumar. An ANSYS model is developed that can predict the behaviour of concrete filled steel tube to determine moment carrying capacity at ultimate point for beam Concrete filled steel tube beams are studied and verified by the finite element program ANSYS against experimental data. The Main parameters affecting the behaviour and strength of concrete filled beams are geometrical parameters, material nonlinearities, loading, boundary conditions and degree of concrete confinement. To account for all these properties ANSYS model is developed. The main parameters varied in analysis study are D/t ratio, characteristic strength of infilled concrete. The proposed model predicts ultimate moment capacity for CFT beams. In the numerical analysis, circular and rectangular CFT cross sections are considered using different grades of concrete. The predicted values are compared with experimental results. Numerical analysis has shown that for rectangular CFT's a good confining effect can be provided. Moment capacity results obtained from the ANSYS model are compared with the values predicted by Lin Han (2004) and different codes such as AISC-LRFD (1999) and EC4 (1994).*

Keywords: *Concrete filled steel tubes, beams, circular tubes, rectangular tubes, composite section, ultimate moment capacity, finite element analysis (FEA) and two-point load.*

I. Introduction

Concrete filled steel tube is a composite material which is currently being increasingly used in the construction of buildings. The use of concrete-filled steel tubular beams in high rise buildings has become popular in recent years. Concrete filled steel tube beams can provide excellent seismic resistant structural properties such as high strength, high ductility and large energy absorption capacity. A reasonable understanding for the behaviour of such columns and beams under earthquake loading is very important. [Hin Lu *et.al* ,2009] presented a finite element analysis (FEA) modeling to study the flexural performance of circular concrete filled thin walled steel tubular beam. The composite action between the steel tube and its concrete core was analyzed.

In the present era, creation of infrastructure facilities for the development of a country is the most important task of Civil Engineers. A multistoried building plays a vital role in the development of infrastructure facilities. In the light of construction of high rise buildings concrete filled steel tubes is one of such an innovative new building material, which can sustain worst combination of loads, with high stiffness and facilitating speeder construction and maintaining economy. [Arivalagan and kandasamy, 2010] presented analytical study on square CFT's beams using ANSYS and verified with experimental data. Concrete filled steel tubular structures are one of the modifications to combined load-bearing structures, which are known as composite or sometimes as complex structures. In addition to the enhancement in structural properties a considerable amount of time can be reduced due to the prevention of permanent formwork.

[Hu *et.al* ,2010] conducted a study on proper material constitutive model for CFT's column of circular cross section and subjected to pure bending moment was proposed. These material models were implemented into the FE program and verified against the experimental data. The concrete forms an ideal core to withstand the compressive loading in the typical applications and it delays and often prevents local buckling of the steel, particularly in rectangular CFT's. [Gho and Lu, 2004] presented a study on steel hallow section infilled with concrete has higher strength and larger stiffness than the conventional structural steel section and reinforced concrete Additionally, it has been shown that the steel tube confines the concrete core, which increases the compressive strength for circular CFT's and the ductility for rectangular CFT's therefore, it is more advantageous to use CFT's. For the columns subjected to the large compressive loading. In contrast to reinforced columns with transverse reinforcement, the steel tube also prevents spalling of the concrete and minimizes congestion of reinforcement in the connection region, particularly for seismic design. Elchalakani *et.al* (2001) presented an experimental investigation of flexural behaviour of circular concrete filled steel tube (D/t=12-110) subjected to large deformation under pure bending. It was found that concrete filling of the steel tube enhances strength, ductility and energy absorption for thinner sections. [Han, 2004] proposed a model that can predict the behaviour of concrete filled hollow structural section.

This paper is an attempt to analyze the flexural performance of CFT's beam in a detailed way by using FEA modeling. The commercial FEA package ANSYS is used in the numerical simulation. This investigation aims to use the FEA modeling to analyze the flexural behaviour, interaction of concrete and steel and load transfer mechanism in circular and rectangular CFT's under pure bending. Material models of concrete and steel, interface model to simulate the concrete and steel interface, element type, mesh, boundary condition and loading. FEA modeling is then used to investigate the stress strain in steel tube and concrete core and the interaction of concrete and steel tube in CFT's subjected to pure bending. Finally the results of experiments are compared with numerical analyses and proposed FE models are verified against the experimental data obtained by the author.

II. Experimental reference model.

Design concrete mix's with characteristic strength of 20, 30 and 40 Mpa using locally available Portland Pozzolana cement (PPC), crushed granite jelly (12mm down) and river sand were used. Mix designs of these three grades of concrete are made based on the guidelines of IS 10262-1978. Mix proportions adopted for the three grades of concrete and 28 days cube strength determined in the laboratory for these mixes are shown in Table 1 Since the steel tube openings are small in size, in order to ensure proper compaction, a higher degree of workability (80-100mm) slump was adopted for these concrete mixes. This was accomplished by using silica fume and a superplasticiser as admixtures. Standard 100mm solid cubes were used to test the compressive strength of the concrete.

Mild steel tubes, cold-formed with yield strength of 250Mpa and 1000mm long were used in the investigation. Flexure test specimens were tested in a 200kN capacity loading frame. In the test setup, at each load point and at the supports of the specimen a set of rollers were placed to allow free rotation. Thus the beam specimens were tested under a simple support condition. The load was applied along two lines spaced at one third of the effective span from either support. Linearly varying displacement transducers were placed at mid-span and at the two loading points. The load was increased gradually until the specimen fails and the corresponding ultimate moment capacity was calculated. LVDT readings are recorded at appropriate load increments and the lateral deflection of the middle segment of the test beam subjected to pure bending was calculated using LVDT data.

If δ1 and δ2 are the deflections under the point loads applied on the test beam. Then net deflection (δn) of the pure bending segment of the test beam is given by

$$(\delta n) = \delta m - \left(\frac{\delta 1 + \delta 2}{2}\right)$$

Table (1): Concrete Mix proportions

Sl. No	Mix Designation	Binder(B) Kg/m^3		Proportions B:FA:CA	W/B ratio	Super plasticizer (%) (by wt of binder)	28 compressive strength (N/mm^2)	Slump (mm)
		Cement	silica fume					
1	M20	370	-	1:1.98:2.51	0.55	1.0	27.8	100
2	M30	390	20	1:1.80:2.28	0.45	2.0	42.0	90
3	M40	410	20	1:1.76:2.16	0.40	2.2	51.0	80

III. Finite Element Method

3.1 Finite Element material model

3.1.1 STEEL TUBE and CONCRETE CORE

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 possessing yield strength (f_y) of 250Mpa, elastic modulus (E) of 200Gpa and for concrete elastic modulus (E) of 5000√fck. The elastic properties are completely defined by giving the Young's Modulus (E) and the Poisson's ratio (ν). By isotropic hardening rule, multilinear stress strain curve was used to model steel. The main parameter for the multilinear stress strain curve is the experimentally measured yield stress (f_y), the ultimate stress (f_{su}) and the ultimate strain (ε_{su}). 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/mm^3. For concrete the Poisson's ratio (νc) of 0.2 and density as 2500kg/mm^3

3.1.2 Element, mesh, contact between steel and concrete, boundary condition

The choice of the element type and mesh size that provide consistent results with less computational time is also important in simulating structures with interface elements. Use of fine mesh size provides accurate results. Type of element for steel tube and concrete is selected from element library in ANSYS. Based on the geometric characteristics of concrete and steel an appropriate element type for the analysis is selected. Beam 188 type element is chosen for concrete and steel. A fine mesh of 3D quadratic BEAM 188 element was used for concrete and steel. Surface to surface contact technique was used to model the interaction between the outer surface of the concrete and the inner surface of the hollow steel tube. The CFT beam is analyzed as full model. The boundary conditions applied for the nodes lying on the planes of symmetry. Beams are supported by rollers. The right surface of beam is supported with **v=0** but allowing displacement to take place in **u** and **z** direction.

The left portion of the beam is symmetry along **z** direction. The load application on the concrete filled steel tubes for beam is based on the test arrangement and modeled as point load at node. All models are generated with a total vertical load of -10kN. An incremental load magnitude along **Y** direction is applied using NEWTON RAPHSON method available in ANSYS library. Each incremental of step in the analysis a small amount of the load is applied until the total magnitude of applied load is reached.

3.2 Basic steps involved in ANSYS

(1) Preprocessing: The major steps in preprocessing are (i) define key points/lines/areas/volumes (ii) Define element type and material/geometric properties and (iii) mesh Lines/areas/ volumes as required. The amount of detail required will depend on the dimensionality of the analysis i.e. 1D, 2D, ax symmetric and 3D (iv) To define contact pairing between the two surfaces if necessary (v) To define constraints (Translational and rotational) (vi) to define loads (point or pressure).

(2) Solver (solution): Here the analysis type is defined like static, transient depending on model we are analyzing. Next step is to set the solution using Solution Controls. Finally solving by incremental method using Newton Raphson solver.

(3) Post processing: In this step we can view the results (i) lists of nodal displacements (ii) element forces and moments (iii) deformed shape and (iv) stress contour diagrams.

3.3 Methodology adopted

- Finite element method has been extensively used to study the structural behaviour of steel concrete composite section. Finite element model is developed using ANSYS 10 version.
- The strength of CFT depends upon the material properties like characteristic strength of infill concrete Young's Modulus (E), Poisson's ratio (v) and stress/stain values. Geometric properties like wall thickness (t), diameter (D) for circular, length (l), width (b), depth(d) for rectangular. Therefore, the material and geometric properties are taken as input parameters for modeling in ANSYS and experimentally obtained moment capacity (M_{Expt}) is the output parameter
- The circular and rectangular CFT's models are developed by varying geometric properties using element BEAM 188. Material properties of concrete and steel are used to develop the model.
- Using BEAM188 element and material properties meshed model is developed and Boundary condition on right and left side of CFT beam is applied by constrained along y direction i.e. v=0. The loading on CFT beam is applied at 1/3rd span from right support in y direction.
- By Incrementing the load using Newton Raphson solver available in ANSYS, Model is analyzed and ultimate moment, deflection values, specific stresses and strain, bending pattern results are obtained from Finite element model.

IV. Results and Discussion

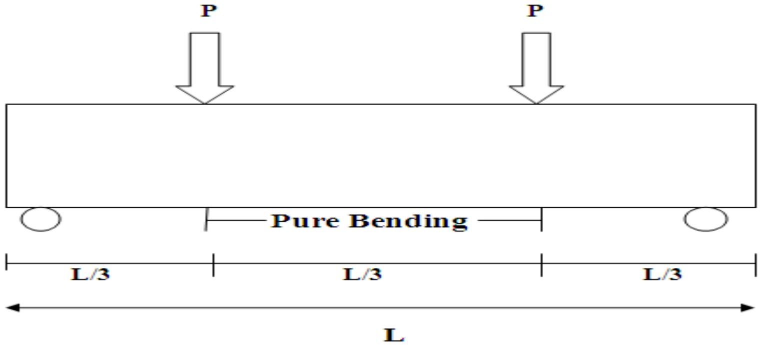

Fig (1): Flexure test on CFT beam

Verification of finite element model is an important step in an analytical study. To verify the accuracy and validity of the finite element model, the model is verified by simulating a number of experimental results. The numerical results obtained from material and geometric nonlinear static analyses are compared with the experimental results of the CFT. The comparison of moment carrying capacity between the test results and finite element model results are presented herein. The experimental results consist of different diameter, length, depth, wall thickness, strength of infill concrete of CFT. The main parameters varied in the test were thickness of steel tube, characteristic strength of in-filled concrete, cross sectional size of the steel tube. The ultimate moment capacity for different geometric property and infill concrete are computed using finite element analysis program. To verify the model experimental results [Manojkumar, 2009] are considered here in and comparison is made between experimental results with results obtained by finite element model.

4.1 Prediction of Moment capacity for circular CFT's beam

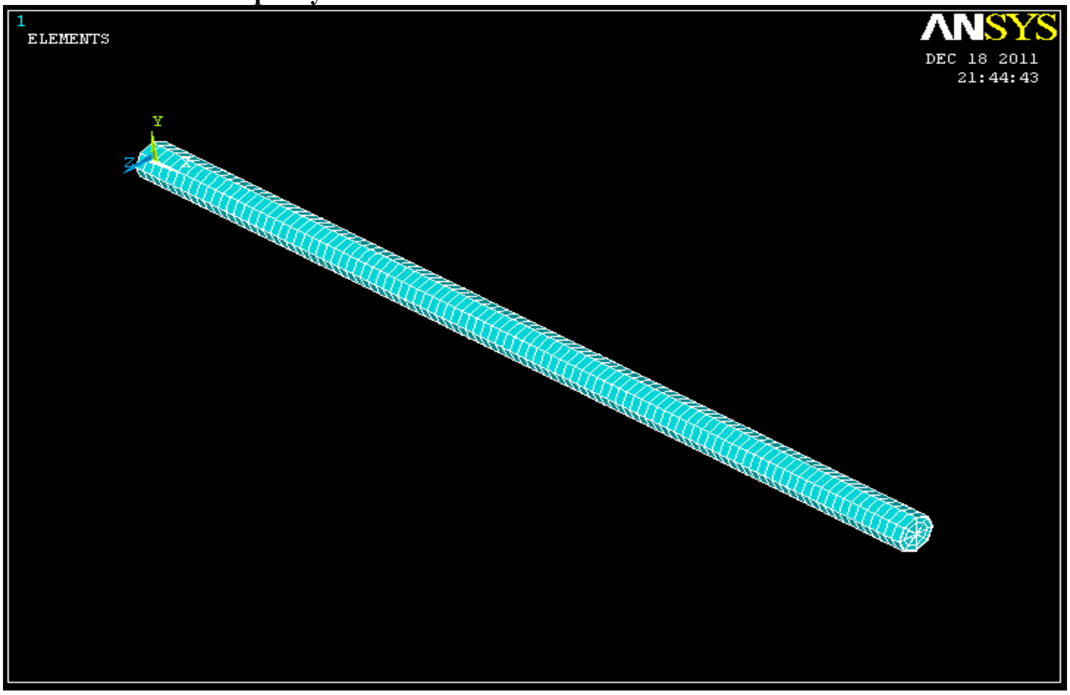

Fig1 (a): circular CFT beam with mesh

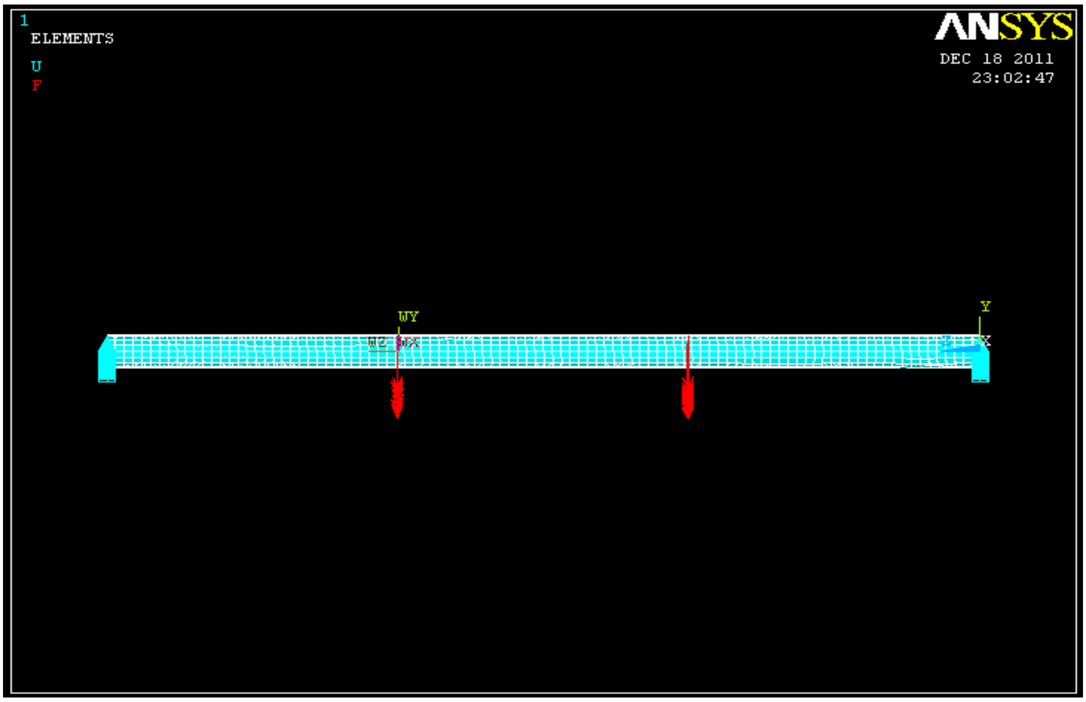

Fig1 (b): Boundary condition with loading for circular CFT beam

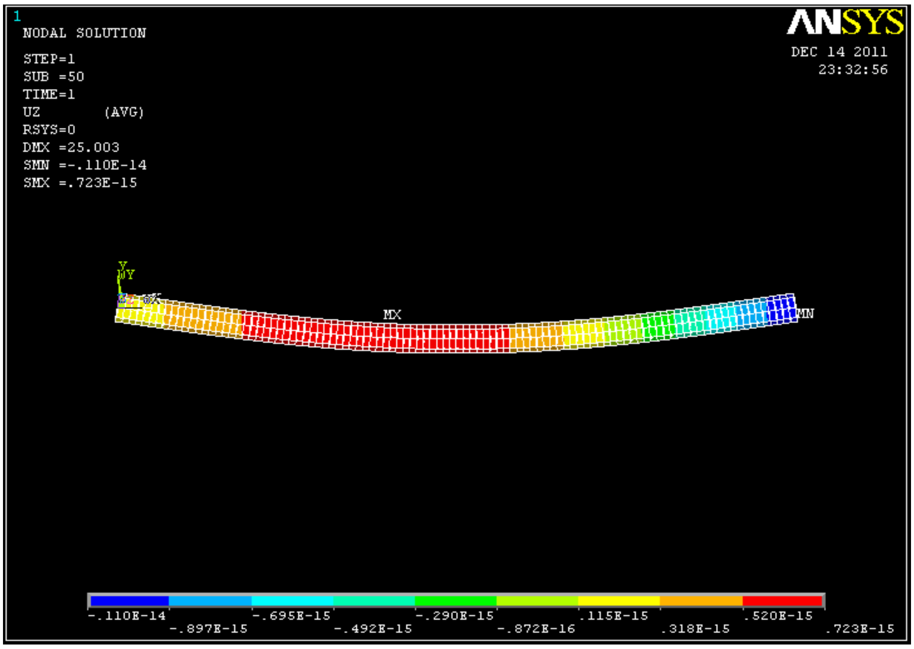

Fig1 (c): Deformed shape of CFT circular beam beyond ultimate load.

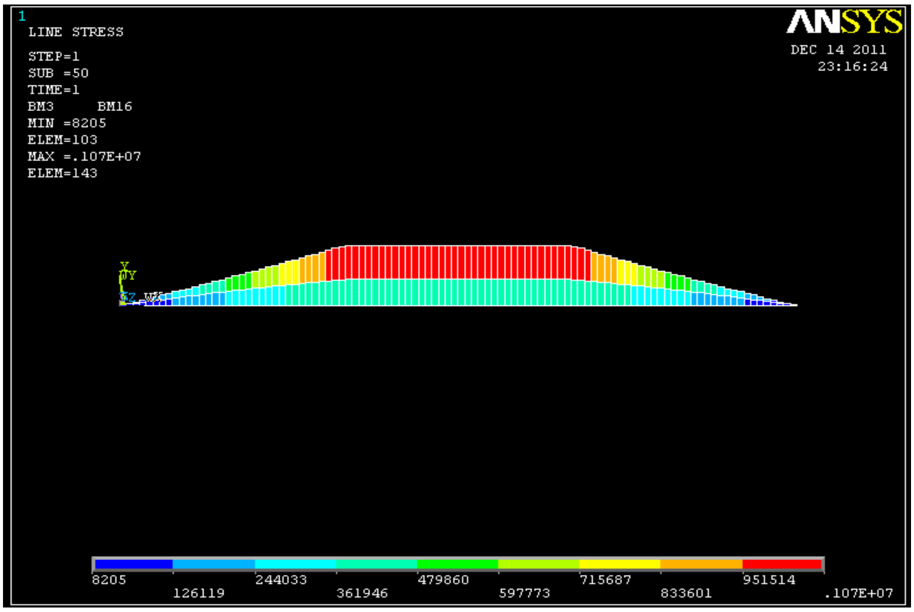

Fig1 (d): Bending moment diagram for circular CFT beam.

Table1 (a): Typical Input and output data for ANSYS validation (circular)

Sl.No	**Input parameters**				**Moment Capacity**
	Diameter D(mm)	**Thickness t (mm)**	**Length L(mm)**	**Cube Strength $f_{ck}(N/mm^2)$**	**M_{Expt}[7] (kNm)**
1	44.45	1.25	1000	40	1.04
2	57.15	2	1000	30	2.33
3	63.5	1.6	1000	20	2.18
4	63.5	2	1000	40	2.93
5	57.15	1.25	1000	40	1.34
6	63.5	1.25	1000	30	2.1
7	57.15	1.6	1000	40	1.95
8	44.45	2	1000	40	1.65

Table1 (b): Comparison of the prediction of ANSYS results and experimental moment capacity results for circular CFT beam

Sl.No	M_{Expt}[7] (kNm)	M_{FEM}(kNm)	M_{Expt}/M_{FEM}
1	1.04	1.07	0.97
2	2.33	2.35	0.99
3	2.18	2.11	1.03
4	2.93	2.84	1.03
5	1.34	1.31	0.99
6	2.10	2.04	1.03
7	1.95	1.90	1.02
8	1.65	1.67	0.98
MEAN			**1.00**
SD			**0.03**
COV			**3.00**

It is observed that prediction by finite element method is consistent.

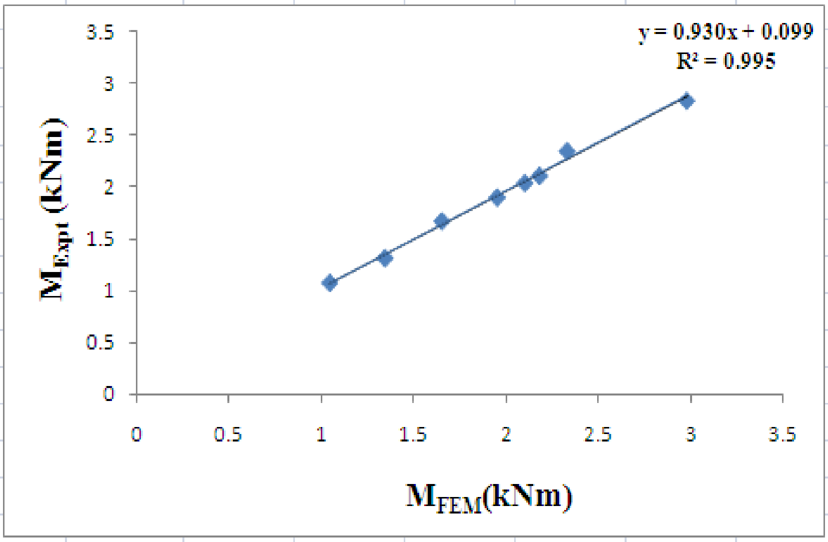

Fig1 (e): M_{Expt} v/s M_{FEM} for circular CFT beam under flexure

4.2 Prediction of Moment capacity for Rectangular CFT beam

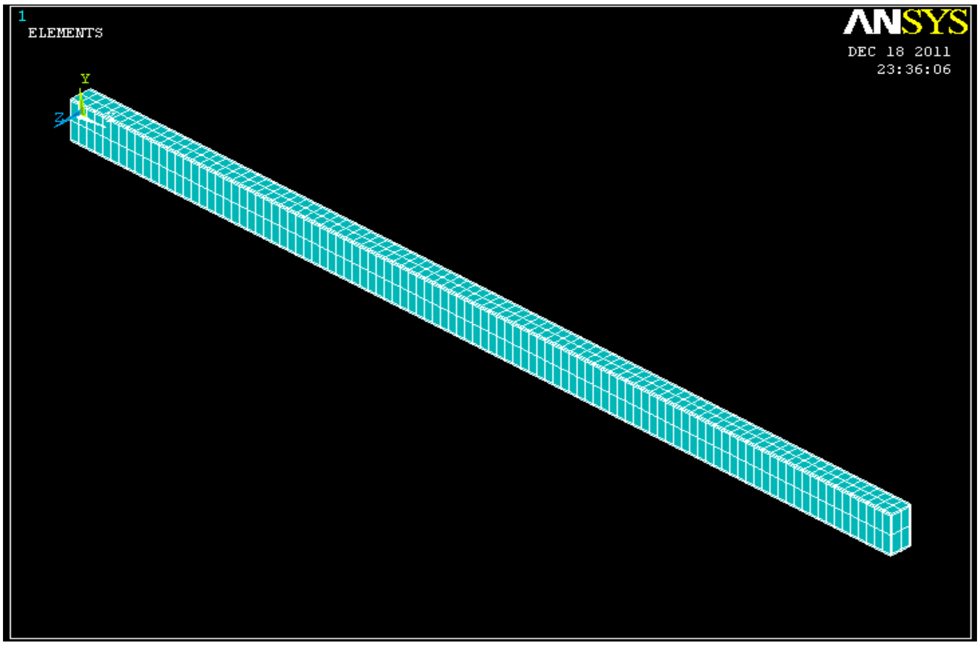

Fig2(a): Rectangular CFT beam with Mesh

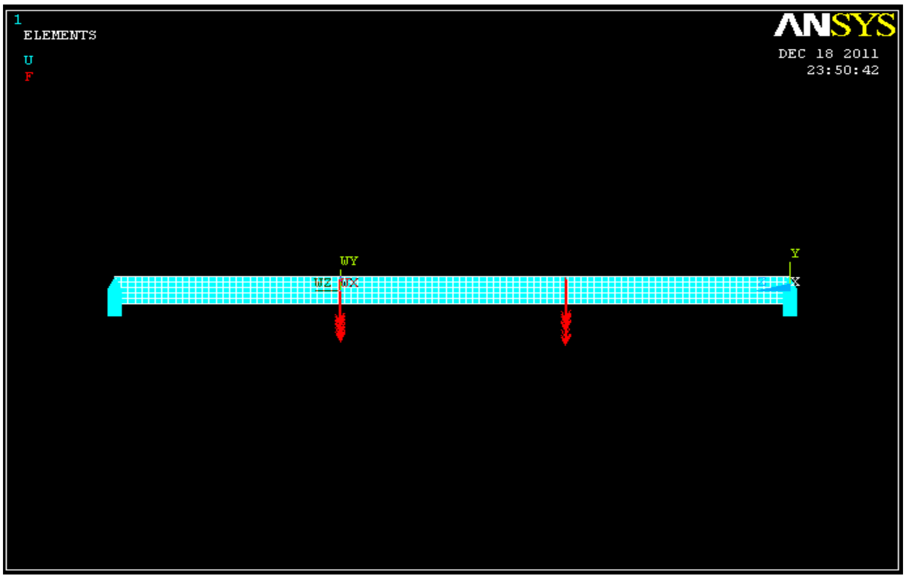

Fig2 (b): Boundary condition with loading for rectangular CFT beam

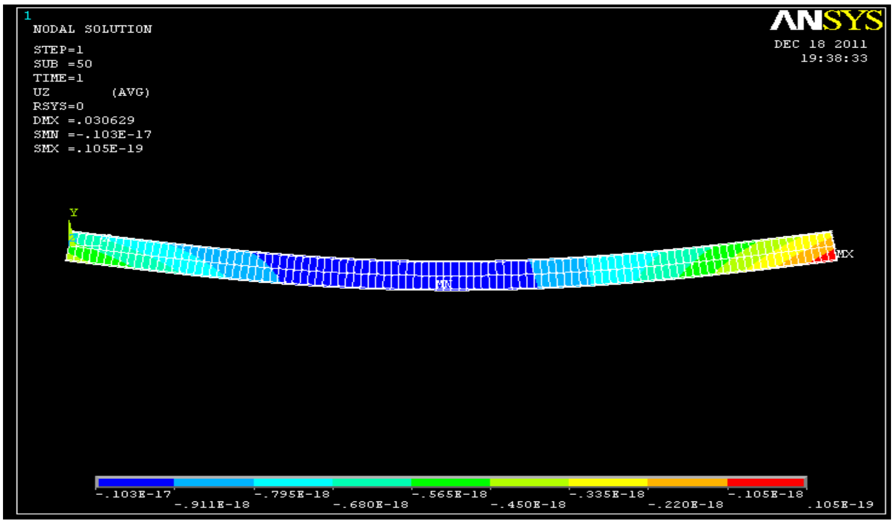

Fig2(c): Deformed shape of rectangular CFT beam beyond ultimate load

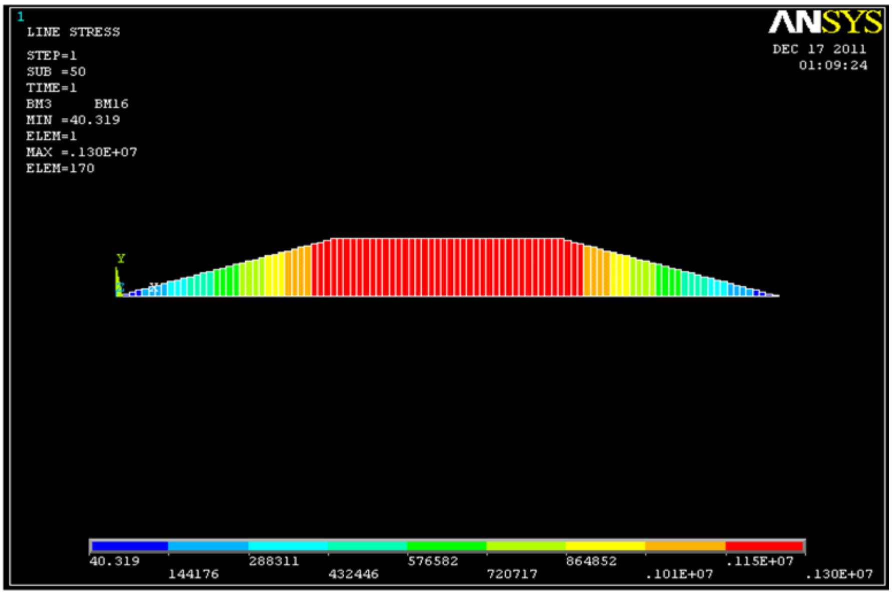

Fig2 (d): Bending moment diagram for rectangular CFT beam

Table2 (a): Typical Input and output data for ANSYS validation (rectangular)

Sl.No	Input parameters				Moment Capacity
	Area A(mm^2)	Thickness t (mm)	Length (mm)	Cube Strength f_{ck}(N/mm^2)	M_{Expt}[7] (kNm)
1	1250	2	1000	20	1.271
2	1250	1.65	1000	30	1.874
3	2400	2	1000	40	2.706
4	3200	1.6	1000	20	3.762
5	3200	2.65	1000	40	5.951
6	2400	2.65	1000	30	4.14
7	1250	1.65	1000	40	1.951
8	3200	2.65	1000	30	5.196

Table2 (b): Comparison of the prediction of ANSYS results and experimental moment capacity results for rectangular CFT beam

Sl.No	M_{Expt}[7] (kNm)	M_{FEM}(kNm)	M_{Expt}/M_{FEM}
1	1.27	1.30	0.98
2	1.87	1.80	1.03
3	2.70	2.77	0.97
4	3.76	3.73	1.01
5	5.95	5.96	0.99
6	4.14	4.09	1.01
7	1.95	1.90	1.02
8	5.20	5.18	1.00
MEAN			**1.00**
SD			**0.02**
COV			**2.00**

It is observed that prediction by finite element method is consistent.

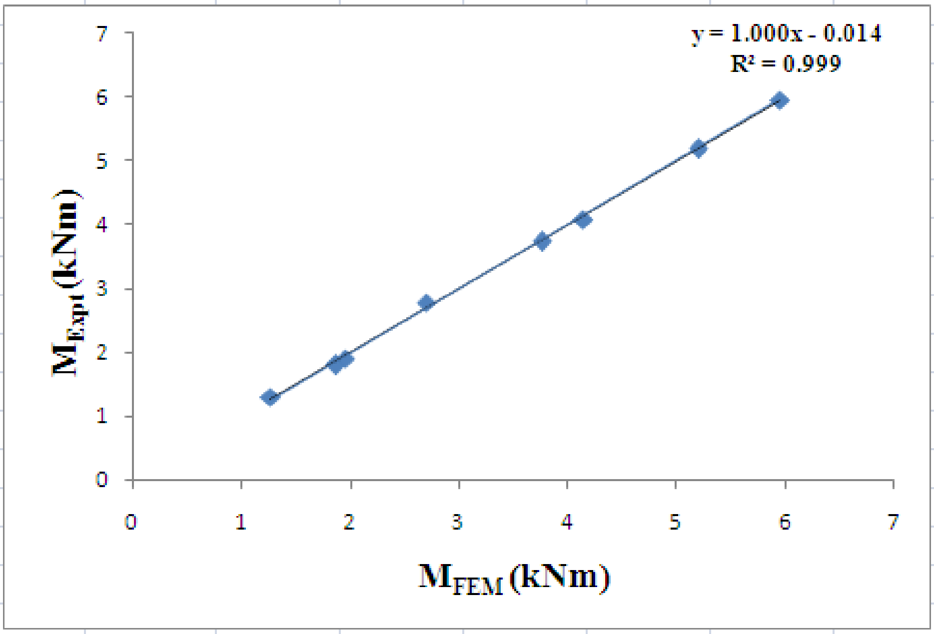

Fig2 (e): M_{Expt} v/s M_{FEM} for rectangular CFT beam under flexure

4.3 Confinement of concrete

Concrete inside the steel tube is confined and the strength of such confined concrete depends upon its own characteristic strength and the thickness of the steel tube. The confinement factor ξ and flexural strength Index γ (FSI) proposed by Lin-Hai Han [2] are used to explain the effect of confinement.

$$\xi = \frac{As \cdot fsy}{Ac \cdot fck} \qquad (1)$$

where A_s and A_c are the cross sectional area of the steel and concrete cor**e,** f_y and f_{ck} are the yield stress of the steel and characteristic compressive strength of concrete.

$$\gamma = \frac{Mu}{Wscm \cdot fscy} \qquad (2)$$

Where W_{scm} = section modulus of the composite beam, given by $BD^2/6$ and $B^2D/6$ about major (x-x) and minor (y-y) axes respectively for composite beams with rectangular section and $\Pi D^3/32$ for circular section; Mu= Moment capacity of the composite beams; f_{scy}=Nominal yielding strength, of the composite sections and flexural strength index, is given by

For concrete filled steel CHS beams

$$f_{scy} = (1.14+1.02\xi).\ f_{ck} \qquad (3)$$

$$\gamma_m = 1.1+0.48 \cdot ln\,(\xi + 0.1) \qquad (4)$$

For concrete filled steel SHS and RHS beams

$$f_{scy} = (1.18+ 0.85\xi).\ f_{ck} \qquad (5)$$

$$\gamma_m = 1.04 + 0.48 \cdot ln\,(\xi + 0.1) \qquad (6)$$

FSI is a measure of moment capacity of a given section with given geometric and material strength properties. FSI increases with increase in confinement factor up to a certain extant and this indicates that better confinement leads to higher FSI. Hence CFT samples with higher grades of infill concrete have performed better only when the wall thickness of the steel tube is also correspondingly increased with increase in the confinement factor. A decrease in the FSI beyond a certain limit indicates that a increase in the wall thickness of the steel tube combined with a lower strength of infill concrete has no beneficial effect on moment capacity of the CFT sections.

4.4 Comparison of ANSYS results with test results, Lin-Han, EC4 and AISE-LRFD.

The moment capacity of the CFT beams are calculated based on the specification in the EC4 1994. The safety factors in the specification were set to unity so that the prediction values obtained in the codes could be used for the comparison with the experimental ultimate moments. [Table3 a and b] It is observed that EC4 (1994) conservatively predicts the moment capacity of CFT sections used in the present FEM analysis results. AISC-LRFD provisions do not consider the effect of the infill concrete and hence the predicted moment capacity values of the CFT samples are again much lower as compared to the experimental results. [Table3 a and b]

Table 3(a): Comparison of moment capacity results obtained by ANSYS model (M_{FEM}) with experimental data, Lin Han model (2004) and different codes for circular CFT's

Sl. No	D (mm)	t (mm)	fck (N/mm^2)	$M_{(LinHan)}$ (kNm)	$M_{(EC4)}$ (kNm)	$M_{(AISC-LRFD)}$ (kNm)	$M_{(Expt)}$ [7] (kNm)	$M_{(FEM)}$ (kNm)
1	44.45	1.25	40	0.684	0.699	0.583	1.04	1.02
2	44.45	2.00	40	1.071	1.031	0.902	1.34	1.36
3	57.15	1.25	40	1.169	1.2	0.977	1.65	1.62
4	63.5	1.25	30	1.384	1.467	1.211	1.95	1.90
5	57.15	1.60	40	1.448	1.48	1.235	2.10	1.97
6	63.5	1.60	20	1.631	1.743	1.521	2.18	2.17
7	57.15	2.00	30	1.712	1.752	1.533	2.33	2.30
8	63.5	2.00	40	2.210	2.241	1.892	2.93	2.79
			Mean	1.300	1.339	1.137	1.799	1.763

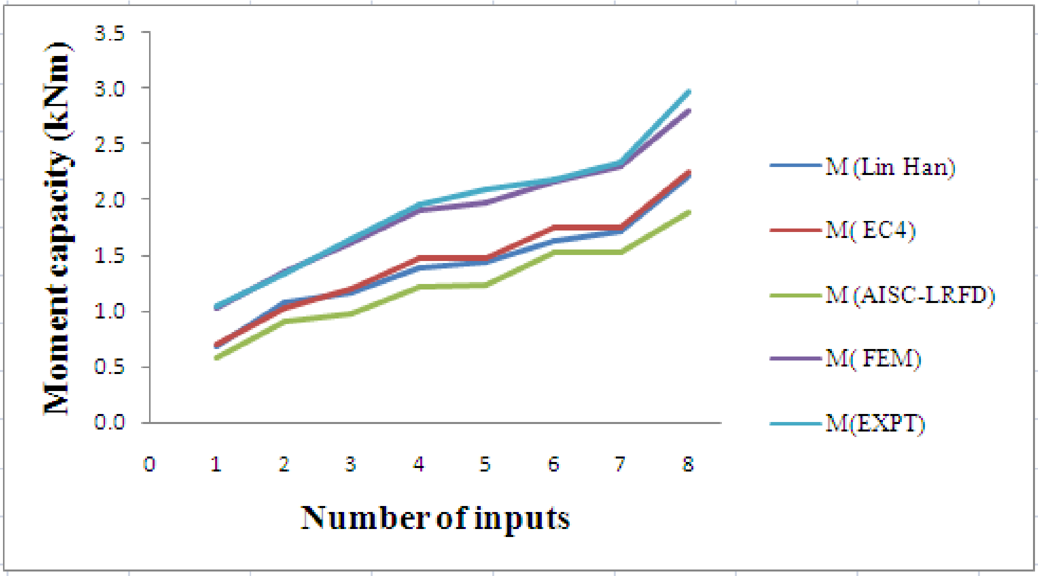

Fig 3(a): Comparison of predicted moment capacity results of ANSYS, Lin Han model (2004), EC4 (1994), AISC-LRFD (1999) with experimental data for circular CFT's

Table 3(b): Comparison of moment capacity results obtained by ANSYS model with experimental data, Lin Han model (2004) and different codes for rectangular CFT's

Sl. No	Area (mm^2)	t (mm)	fck (N/mm^2)	$M_{(LinHan)}$ (kNm)	$M_{(EC4)}$ (kNm)	$M_{(AISC-LRFD)}$ (kNm)	$M_{(Expt)}$[7] (kNm)	$M_{(FEM)}$ (kNm)
1	1250	2	20	2.256	1.221	1.129	1.27	1.23
2	1250	2.65	30	3.219	1.567	1.446	1.87	1.91
3	1250	2.65	40	3.24	1.598	1.446	1.95	1.94
4	2400	2	40	4.077	2.272	1.944	2.70	2.64
5	3200	1.6	20	4.333	2.79	2.434	3.76	3.82
6	2400	2.65	30	5.278	2.806	2.511	4.14	4.12
7	3200	2.65	30	7.559	4.419	3.898	5.20	5.24
8	3200	2.65	40	7.795	4.534	3.898	5.95	5.89
			Mean	4.280	2.382	2.115	2.984	2.986

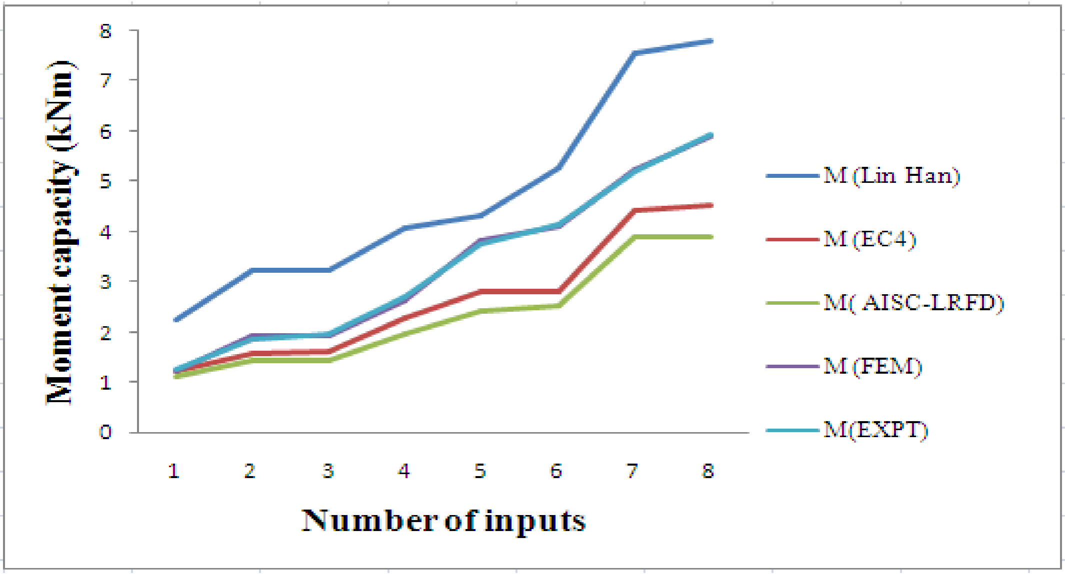

Fig 3(b): Comparison of predicted moment capacity results of ANSYS, Lin Han model (2004), EC4 (1994), AISC-LRFD (1999) with experimental data for rectangular CFT's

Moment capacities of all the test samples are determined by the theoretical models proposed byLin-Hai Han [2]. The model estimates quite satisfactorily the moment capacity of CFT samples tested here in, even though they have diameters in the range of 44.45-63.5 mm. The estimates are within the experimental values and it is found that the predicted estimates are much too conservative as compared to actual moments. [Table 3 a and b]

V. Conclusion

An accurate finite element model for the analysis of concrete filled steel tube beams are estimated using stress stain curves for steel tube and concrete. From the finite element analysis carried out for CFT beams following conclusions are drawn

1. It is found that finite element model predicts moment capacity at ultimate point for circular, rectangular CFT's quite agree with those determined from actual experiments.
2. Coefficient of variance (COV) between results predicted from finite element model with that of experimental results for Circular 3.00 and rectangular is 2.00 hence, the predicted value moment capacities for circular and rectangular cross sections found to give good results without conducting experiments.
3. It can be concluded that the numerical values predicted by FEM for rectangular show better results compared to circular CFT beams.
4. To verify the accuracy of predicted model large experimental data may be used. Such finite element models save the cost and time of experimentation to compute moment capacity of circular, rectangular CFT's.
5. The percentage of error for moment capacity of CFT beams predicted using ANSYS, EC4 (1994), Lin Han formula (2004) and AISC-LRFD (1999) for circular section are 2.00, 25.56, 27.74, 36.77% respectively; for rectangular section are 0.048, 20.19, 43.43, 29.11% respectively. This concluded that ANSYS results for circular, rectangular have less percentage of error. Thus, it can be used to get better results without conducting experiments.

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