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Comparison of Experimental values with Analytical Evaluation of Concrete Filled Steel Triangular Fluted Columns for Concentric Load

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Abstract: **Both experimental and analytical investigation using ANSYS program have been performed on 2500 mm long with 0.8 mm thick steel core. These cores were placed with #8 diameter rods of Fe 415 as reinforcement and filled with M_{20} grade self compacting concrete. Concrete Filled Steel Fluted Columns (CFSFT) with and without longitudinal reinforcement. Behaviour of concrete filled steel fluted columns having triangular flutes have been investigated by conducting experiment on thirteen columns. The parameters that have been chosen for the study are L/D ratios of 15, 20 and 25 and the number of reinforcements 3, 4, 5 and 6 of #8. The columns were placed on smooth plates at both ends and the columns were axially loaded and have been analysed for its stiffness and strength which have been presented. The percentage increase in strength from ANSYS specimens were 6.25%, 6.02% and 12.59% respectively. Axial deformation obtained from experiments in stiffness for L/D ratios of 15, 20 and 25 70.61%, 62.69% and 63.18% increased as compared to ANSYS.**

Keywords: **CFST, CFSFC, SCC, Triangular Flutes, Stiffness, Strength.**

1. INTRODUCTION

Substantial efforts have gone into understanding the behaviour of CFST columns to develop a better composite columns. Emphasis has been made with regard to, shape of the column, L/D ratio, type of failure of the members depending upon the shape and boundary condition of the column. Study has been made both on experimental and analytical investigations.

Technology of concrete filled steel tubular column was evolved as early as 1970's, itself, and there has been enough research carried out to understand the complete behaviour of these columns. CFST is a composite structural member, which resists the applied loads through the composite action of steel as well as concrete. The interactive and integral behaviour of concrete and structural steel elements makes it a cost effective alternative. In addition to its improved load carrying capacity, it is also aesthetically pleasing. Due to the presence of concrete core, local buckling of steel tube is delayed and the strength deterioration after local buckling is moderated, both due to restraining effect of concrete. The strength of concrete is increased, due to the confining effect provided by steel tube and on other hand the strength deterioration is not that severe because concrete does not spall due to the confinement. Drying shrinkage and creep of concrete are much smaller in these columns as compared to other structural forms. Having listed all the advantages, however the major disadvantage of a composite column is the exposure of tube to the environmental effects (such as heat, cold, UV etc). For steel tubes, this raises concerns related to susceptibility to corrosion and fire safety. The structural properties of CFST columns include high strength, high ductility and high energy absorption capacity. The load carrying capacity and behaviour in compression, bending and shear are all superior to reinforced concrete. The reduction of the steel tube thickness in thin-walled CFST columns has the potential to significantly reduce construction costs. The load carrying capacity and behaviour in compression, bending and shear are all superior to reinforced concrete. Currently there is no comprehensive design standard that can be used for the design of thin-walled CFST columns. Extensive research have been conducted on steel-concrete composite columns in which structural steel encases concrete.

The CFST fluted column is a structural member which resists the applied loads through the composite action of steel and concrete. However, the effect of confinement is required to be studied. Here a new approach of confining concrete by providing triangular shaped fluting is being investigated by a well planned experimental work on concrete filled steel fluted columns. The parameter adopted for the study were (i) different shapes of fluted steel tubes. (ii) Different L/D ratio (iii) Without reinforcement and varying the number of reinforcements from 3 to 6 Results have been analyzed for M_{20} Self Compacting Concrete (SCC) specimens with respect to buckling characteristics, load deformations, stress strain characteristics, stiffness and strength.

2. EXPERIMENTAL SETUP

No Reinforcement 3#8 4#8 5#8 6#8

Fig 1. Triangular Fluted Steel Tube With and Without Reinforcement

Fig.2.Experimental Setup Fig. 3. Overall Experimental Setup with Theodolite

2.1 Experimental Programme

Thirteen concrete filled triangular fluted column test specimens with L/D= 15, 20, 25 and thirteen concrete filled rectangular fluted column test specimens with L/D = 15, 20, 25 were tested under concentric axial compression. All the columns were circular in shape provided with five triangular shaped and rectangular shaped fluting running the length of the column. The steel fluted core was obtained by pressing a plane mild steel sheet at 5 different locations in triangular shape and rectangular shape. The resulting section was then closed by using tack and arc welding, which was continuous throughout the length of the column. All the specimen were 2500 mm tall and 0.8 mm thick In all columns were designed by using self compacting concrete M_{20} grade of concrete. Test was conducted in a loading frame of capacity 100 tones, using a hydraulic jack of capacity 2000 kN with an accuracy of 10 kN. Initial seating of load of 50 kN was applied and all the temporary supports were removed. The alignment of the column was Faculty of Engineering-Civil verified at the same time. At the outset , the increase in axial deformation with the increase in load was found to be marginal. The columns were placed restraining rotation at both ends and the loads were applied without shock at an increment of 50 kN until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained. Special attention was given to verifying the correct position of the column, before any loading. After completing the initial set up the specimen were placed on the loading jacked to fix the specimen between two supports. Care was taken to maintain vertically along both vertical plane and line of action of load and loading axis . The maximum load and load applied to the specimen was then recorded and the appearance of the concrete and any unusual features in the type of failure noted. For details refer Tables 1.

Table. 1. Total Number of Specimens For Triangular Fluted Columns

Sl No	Name of the Specimen	Mean Diameter	Thickness of Steel Tube	L/D ratio	Length of Column
1	CFSFC-TFC-NR-D167	167	0.8	15	2500
2	CFSFC-TFC-3/#8-D167	167	0.8	15	2500
3	CFSFC-TFC-4/#8-D167	167	0.8	15	2500
4	CFSFC-TFC-5/#8-D167	167	0.8	15	2500
5	CFSFC-TFC-6/#8-D167	167	0.8	15	2500
6	CFSFC-TFC-NR-D125	125	0.8	20	2500
7	CFSFC-TFC-3/#8-D125	125	0.8	20	2500
8	CFSFC-TFC-4/#8-D125	125	0.8	20	2500
9	CFSFC-TFC-5/#8-D125	125	0.8	20	2500
10	CFSFC-TFC-6/#8-D125	125	0.8	20	2500
11	CFSFC-TFC-NR-D100	100	0.8	25	2500
12	CFSFC-TFC-3/#8-D100	100	0.8	25	2500
13	CFSFC-TFC-4/#8-D100	100	0.8	25	2500

Where, CFSFC - Concrete Filled Steel Fluted Column ,

TFC - Triangular Flute Column , 3/#8 - 3 bars of 8 mm diameter of reinforcement

NR - No reinforcement 4/#8 - 4 bars of 8 mm diameter of reinforcement

D167- Diameter of the column 167 mm, 5/#8 - 5 bars of 8 mm diameter of reinforcement

D125- Diameter of the column 125 mm, 6/#8 - 6 bars of 8 mm diameter of reinforcement

D100- Diameter of the column 100 mm.

3. ANALYTICAL EVALUATION

3.1 Analysis

The ultimate purpose of a finite element analysis is to recreate mathematically the behaviour of an actual engineering system. In other words, the analysis must be on accurate mathematical model of a physical prototype. In the broadest sense, this model comprises all the nodes, elements, material properties, real constants, boundary conditions and other features that are used to represent the physical system. Hence due to the presence of GUI platform solid modelling can be done with ease.

The steel tube and the concrete have to be separated from each other to simulate the bond between them. Therefore they were defined as individual bodies. A three dimensional Finite Element model based on solid elements was established and interface between the steel tube and concrete were simulated by using surface based interaction with a coulomb friction model.

In this Finite Element model, the steel tube has been modelled by element SHELL181, the concrete by element SOLID65 , the reinforcement by using PIPE16 and the rigid body element by PLANE42 & LINK8 which was used to apply the nodal forces, if any, should be input per unit of depth for a plane analysis and on a full 360^o basis for an axisymmetric analysis.

3.1.1 Parameters Considered

As in the case of experimental analysis, triangular and rectangular fluted columns for various L/D ratios of 15, 20 and 25 with number of reinforcements being 3, 4, 5 and 6 number of reinforcements have been analysed**.** For comparison, one column for all the L/D ratios, without reinforcements have been analysed.

3.1.1.1. Element Properties

a. Geometric Properties

The fluted columns were circular in shape with a mean diameters of 167mm, 125 mm and 100 mm with five flutes along the circumference which runs throughout the length of the column. The height of the columns were 2500 mm.

b. Material Properties

The material properties of concrete, steel sheet and the reinforcement rods have been shown in the following Table.1. These numerical are those which were obtained by conducting tests on the sample materials**.** The yield strength of steel reinforcement is 421.29 N/mm^2 and the yield strength of steel sheet is 144.61 N/mm^2. The compressive strength of concrete has been 20 N/mm^2.

Table 3: Materials properties of different materials .

Sl No	Materials	Poisson's ratio μ	Modulus of Elasticity E N/mm^2	Remarks
1	Concrete	0.16	0.223×10^5	Split tensile strength test
2	Reinforcement	0.28	0.21×10^5	Tensile test
3	Steel Sheet	0.26	0.723×10^5	Tension coupon test

3.1.1.2 Meshing

It is a procedure for generating a mesh of nodes and elements constituents. Before meshing the model, it is important to think about whether a free mesh or a mapped mesh is appropriate for the analysis. A free mesh has no restrictions in terms of element shapes and has no specified pattern applied to it. Compared to a free mesh, a mapped mesh is restricted in terms of the element shape it contains and the pattern of the mesh. In this analysis free mesh with tetrahedral elements have been used.

3.1.1.3 Boundary Conditions

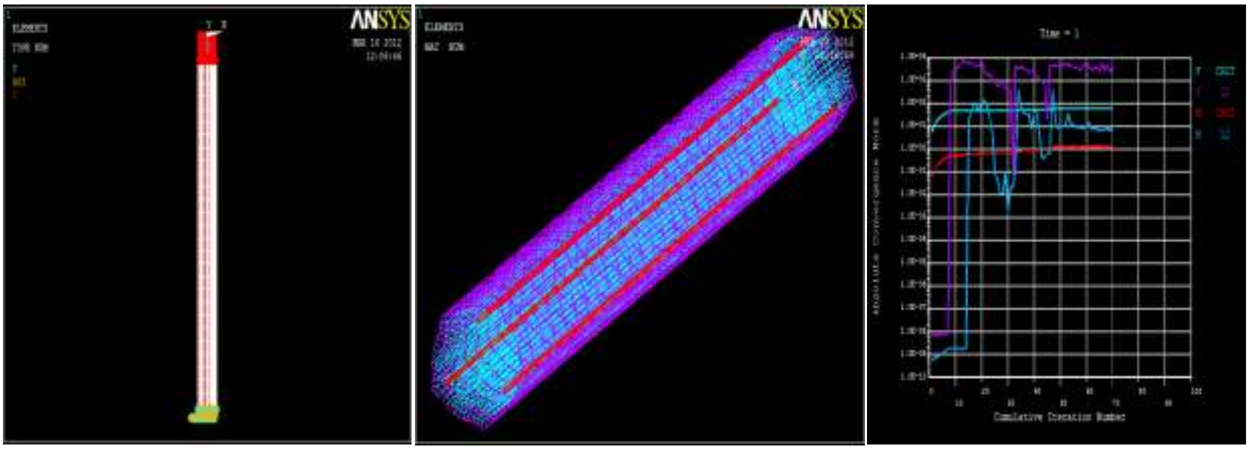
Boundary conditions were enforced on the bottom surface. The top surface of the column is fixed with dx = dy = 0, allowing displacement to take place in z direction.

3.1.1.4 Loading

The uniform compressive loading in z direction is applied to the top surface of the column directly in the form of pressure to concrete and steel casing and also reinforcement. The buckling loads are critical loads where certain type of structures becomes unstable and buckles with a large deflection occurred due to small increase in force. A incremental force of 50 kN has been applied in the axial z-direction.

3.2 Analytical Procedure

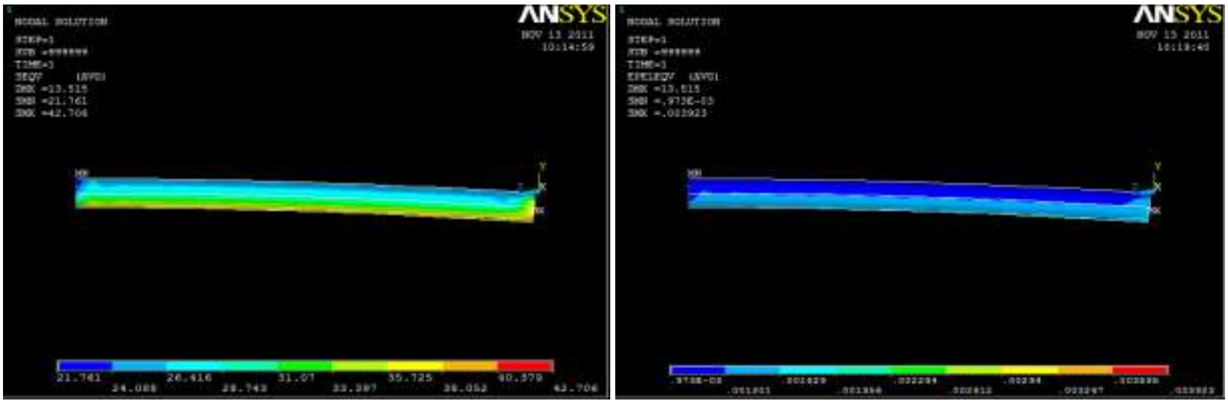
Modelling of each of the materials and the combined column element with the boundary conditions are depicted in Fig 4 (a,b,c). These are for various number of reinforcements with L/D ratio 15 (D167), 20 (D125), 25 (D100). Here, the procedure is explained for triangular fluted columns only. Similar procedure has been followed for rectangular fluted column also.



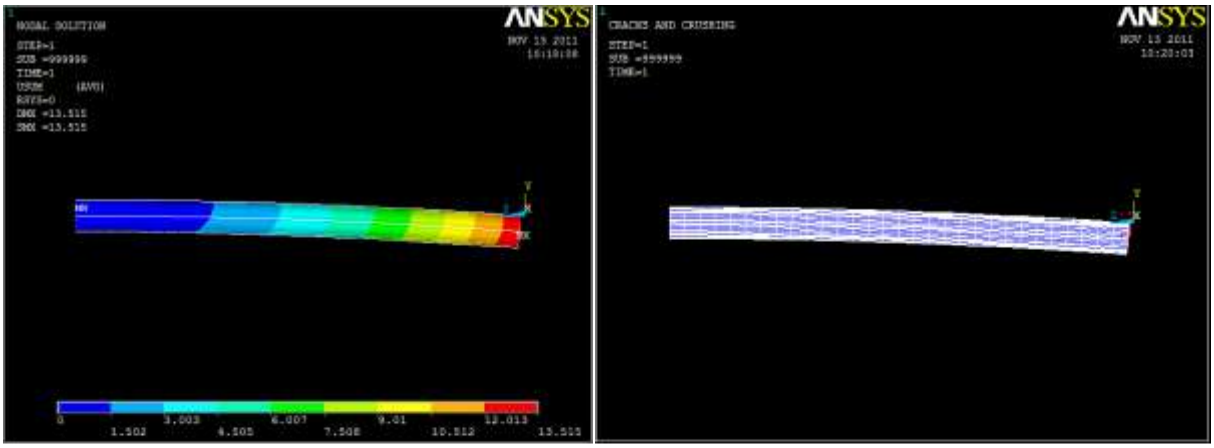
a. Boundary Condition b. Skeletal Column c. Absolute Convergence Norm

Fig 4. Models of TFC for CFSFC (3/#8- L/D = 15)

Results for TFC stress, strain and displacement variation have been shown in Fig 5 (a,b,c,d)



a: Stress Variation in the Concrete Core b: Strain Variation in the Model



c: Displacement Variation in the Model d: Cracking and Crushing of the Model

Fig 5. Results of TFC for CFSFC (3/#8- L/D = 15)

4. RESULTS AND DISCUSSION

4.1 Triangular Fluted Column (TFC)

4.1.1. Length to Depth ratio 15 or D167

a. Stress in the Columns

Curves drawn for Load vs. stress in Fig. 6, shows that they follow the same path as that of the curves for experimental results. Deviation has been observed to be increasing as the number of reinforcement increases. The discrepancy between ANSYS and experimental results in the case of no reinforcement (nr), 3, 4, 5 ,6 number of reinforcement in columns are 3, 4, 4, 6, and 17 percentage increased in analytical results as compared to the experimental values at the failure load. No deviation has been observed in the case of column with no reinforcement.

b. Strain in Columns

Fig. 7. shows that overall strain observed from ANSYS varies linearly up to almost 700 kN i.e., up to about 85% of the total load. Where the column has yielded and later the strain has increased for small incremental load showing that the column have reached plastic stage. Experimental results have shown little different behaviour with strain not increasing in the manner as it has increased in the case of ANSYS results when the load is increased with which distinctly, two different behaviours have been observed between experimental and analytical results. The maximum strain observed with ANSYS is about 95% of the experimental results for the column with no reinforcement. Similar results have been observed for other columns.

c. Deformations in Columns

Analytical method has estimated conservative values of axial deformation as compared to the experimental results by 83, 19, 78, 80 and 77 percent with no reinforcement, 3, 4, 5 and 6 number of reinforcement for L/D = 15. Both the experimental and analytical results have shown linear variation for no reinforcement and 5 and 6 number of reinforcements in columns. Non linear behaviour can be observed in the results of experiments for 3 and 4 number of reinforcements, as shown in Fig. 8

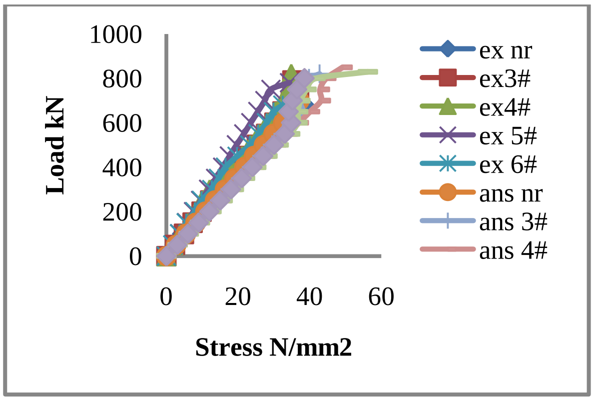


Fig. 6. Stress in the column for TFC with L/D = 15

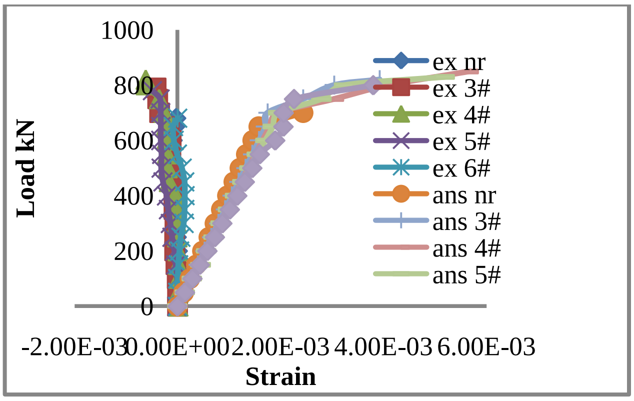


Fig. 7. Strain in the columns for TFC with L/D = 15

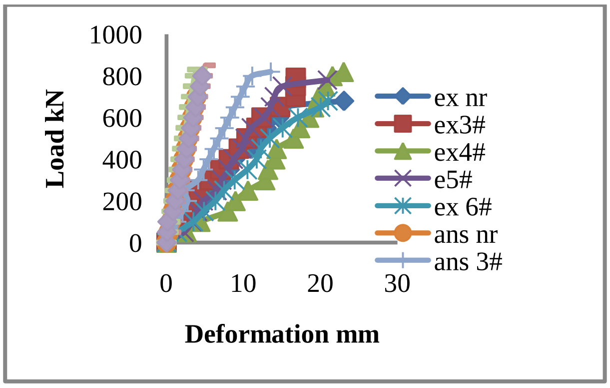


Fig. 8. Deformation in Columns for TFC with L/D = 15

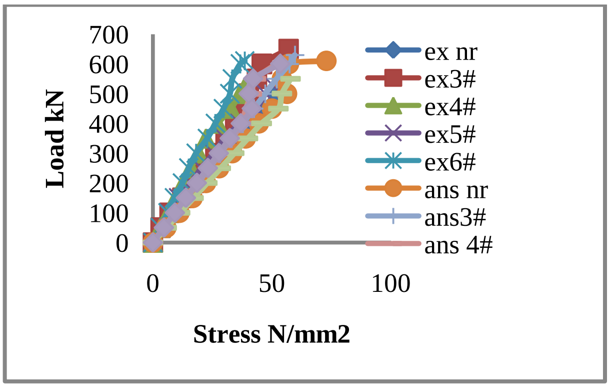


Fig. 9. Stress in the Column for TFC with L/D = 20

4.2.1 Length to Depth ratio 20 or D125

a. Stress in the Columns

It can be observed from the Fig. 9. which illustrates the Load vs. stress behaviour for the column that they follow the same path as that of the curves for experimental results. Deviation has been observed to be increasing as the number of reinforcement increases. The discrepancy between ANSYS and experimental results in the case of no reinforcement (nr), 3, 4, 5 ,6 number of reinforcement in columns are 22, 3, 15, 4 and 2 % increased in analytical results as compared to the experimental values at the failure load.

b. Strain in Columns

Fig. 10 shows that overall strain observed from ANSYS varies linearly upto almost 450 kN i.e., upto about 66 % of the total load where the columns have yielded and later the strains have increased for small incremental load showing that the columns have reached plastic stage. Experimental results have shown little different behaviour with strain not increasing in the manner as it has increased in the case of ANSYS results when the load is increased.

It is observed that the strains in columns have decreased as compared to number of reinforcements by 6, 10, 5, 4 and 1% for 3, 4, 5 and 6 number of reinforcements respectively. The strains observed with ANSYS is about 88, 74, 96, 89 and 89 % of the experimental results for the column with no reinforcement,3, 4, 5 and 6 number of reinforcements in the columns.

c. Deformations in Columns

Fig. 11 illustrates the load- deformation behaviour for the columns for both finite element analysis and the experimental results. It reveals that the maximum deflections estimated by FEA are comparatively quite less and are 73, 64,23 60 and 83 % for no reinforcement, 3, 4, 5 and 6 number of reinforcement respectively in columns.

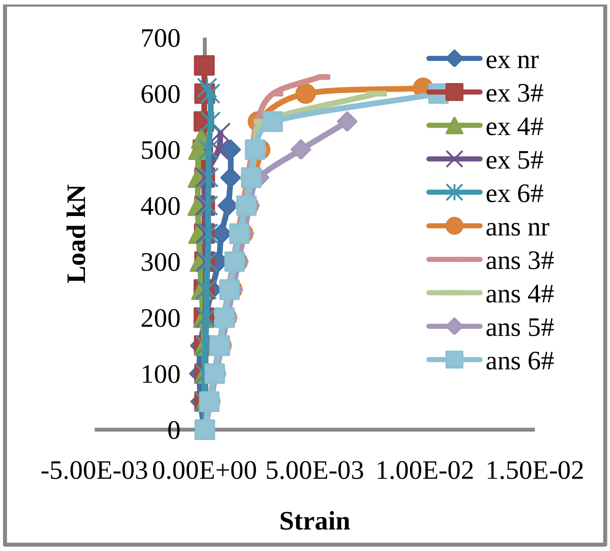


Fig. 10. Strain in the Columns for TFC with L/D = 20

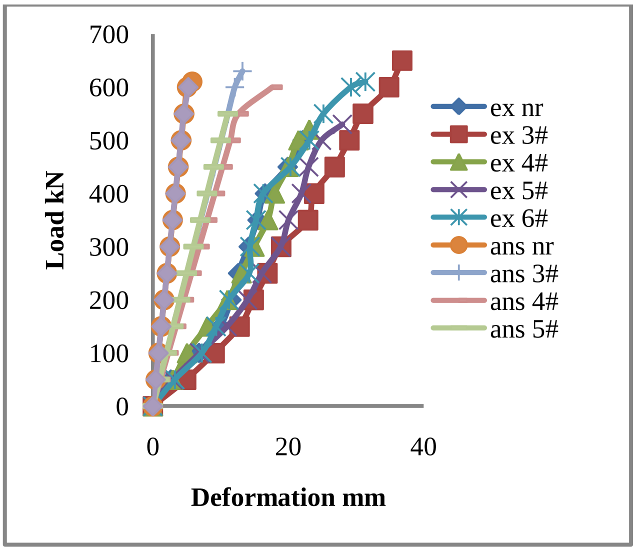


Fig. 11. Deformation in columns for TFC with L/D = 20

4.3.1 Length to Depth ratio 25 or D100

a. Stress in the Columns

Fig. 12. shows that the load vs. stress behaviour for the columns for both analytical and experimental values. It reveals that behaviour of columns for stress in all the three columns of no reinforcement, 3 and 4 number of reinforcements are similar with 27% decreased in stresses in both the columns of 3 and 4 number of reinforcements as compared to the column with no reinforcement. It is observed that the FEA results have close agreement with experimental results and in the case of no reinforcement, 3 and 4 number of reinforcements in the columns the stress have increased by 40, 23 and 17 % respectively as compared to the experimental results at the failure load results have close agreement.

b. Strain in Columns

Fig.13 shows that overall strain observed varies linearly upto almost 350 kN that is upto 72 % of the total load. Distinctly two different behaviours have been observed between experimental and analytical results. the three graphs drawn for no reinforcement, 3 and 4 number of reinforcement behave in a similar way but are different from that of experimental results. The maximum strain observed with ANSYS is about 92, 90 and 76 % of the experimental results for the column with no reinforcement 3 and 4 number of reinforcements in the columns.

c. Deformations in Columns

Analytical values have estimated conservative values of axial deformation as compared to the experimental results by 16, 75 and 85 percent with no reinforcement, 3 and 4 number of reinforcement. Both the experimental and analytical results have shown linear variation for 3 and 4 number of reinforcements in columns. Even it can be observed that though the experimental and analytical results do not concur each of the experimental and analytical results agree in their behaviour as shown in Fig 14.

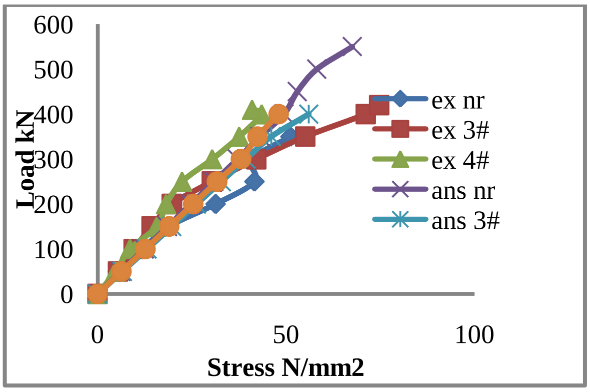


Fig.12 Stress in the Column for TFC with L/D = 25

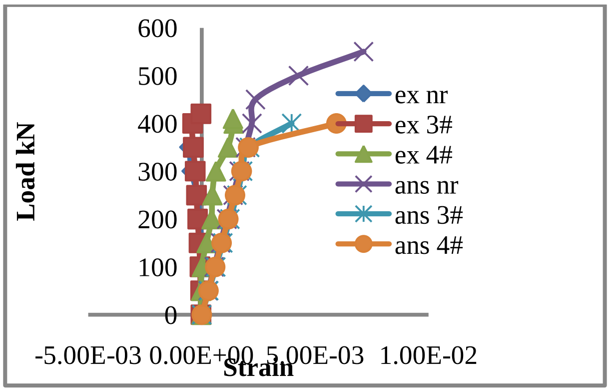


Fig.13. Strain in the Columns for TFC with L/D = 25

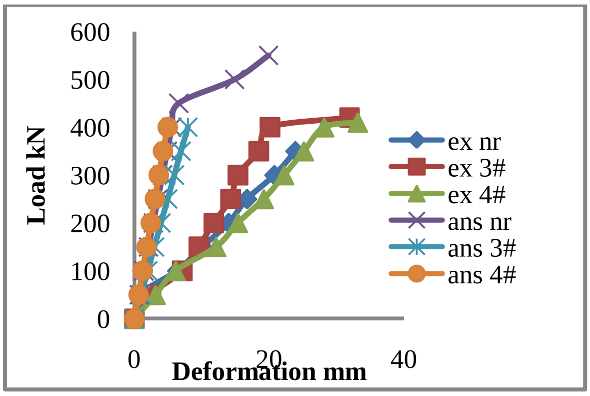


Fig. 14. Deformation in Columns for TFC with L/D = 25

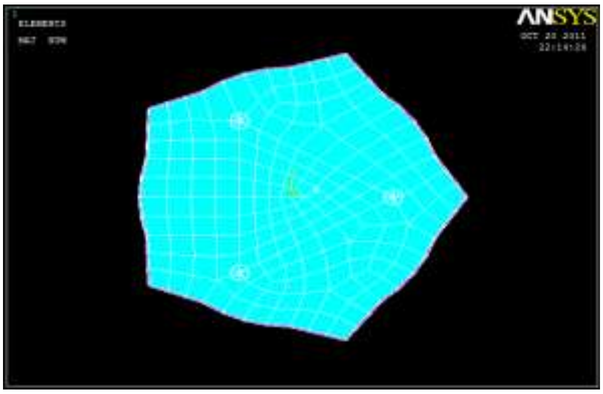
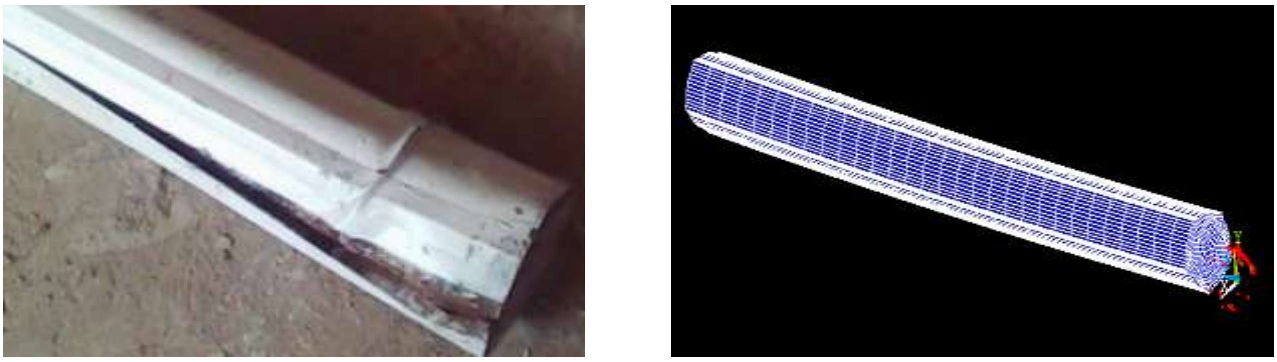


Fig 15.Cross Section of CFSFC-TFC-3#8-D167 (ANSYS MODEL)



Experimental Ansys

Fig.16. Failure of Triangular Fluted column by Experimental & Analytical (Ansys)

5. CONCLUSION

STRENGTH

- The strength obtained from experiments for L/D ratio of 15, 20 and 25 specimens were on the conservative side. The percentage increase in strength from ANSYS specimens were 6.25%, 6.02% and 12.59% respectively.
- For L/D ratio of 15, 20 and 25 , the value of stresses from experiments were 18.97% , 32.72 % less and 8.42 % more as compared to ANSYS.

STIFFNESS

- Axial deformation obtained from experiments for L/D ratios of 15, 20 and 25 70.61%, 62.69% and 63.18% increased as compared to ANSYS.
- The maximum axial deformation obtained from experiments for L/D ratio of 15 , 20 and 25 were 23.05 mm (NR), 36.82 mm (3//#8) and 33.14 mm (4//#8). From Ansys 13.51 mm (3/#8) , 17.65 mm (4/#8) and 19.91 (NR).

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