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BEHAVIOR OF 4-LACED CONCRETE FILLED STEEL TUBE COLUMN UNDER AXIAL COMPRESSION

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Abstract

In this paper, a comparative analytical study of concrete-filled steel tubular (CFST) laced columns is presented for circular and octagonal cross-section with shear connectors. These columns consist of four concrete-filled steel tubes are laced together. An analytical study was performed to quantify the column failure mechanism at ultimate loads. The study shows that the resulting load-deflection curves. These curves were then used to quantify the structural behavior of each element of the 4laced CFST column. The analysis results indicate that the compression force in the longitudinal members dominated the failure mechanism in the 4-tube laced CFST columns. In-plane bending occurred when member segments reached the compression failure load. Due to confinement effects, octagonal 4-tube laced CFST columns have a lower maximum load capacity than circular 4-tube lace CFST columns. The load carrying capacity of octagonal CFST with shear connectors provided is more than that of circular 4-tube laced CFST column without shear connectors. The lacing elements (diagonal and horizontal braces) were found to have low forces and remain within the elastic range until failure. Analytical studies have shown that load-bearing capacity decreases with increasing aspect ratio and eccentricity.

Keywords: - CFST, d/t ratio, Finite-element analysis, Ultimate load, shear connectors

1. Introduction

Steel-concrete composite columns were used for more than a century. At the early stages it was used to provide fire protection to steel structures. Afterwards, the concrete encased columns strength properties were also considered in the design. However, the research into concrete filled steel tubes (CFST) failed to begin until the 1960s.

Nowadays, the composite structural elements are increasingly used in tall buildings, bridges and other types of structures. Because of its composite effects, the disadvantage of two materials can be compensated and the advantages can be combined providing efficient structural system. The steel-concrete composites are considered as a beneficial system for carrying large axial load benefitting from the interaction between the concrete and the steel section (6). The steel section reinforces the concrete to resist any bending moments, tensile and shear forces. The concrete in a composite column reduces the potential for buckling of the steel section in addition to resisting compressive loading. There are two types of steel-concrete composite columns which are commonly used in buildings. Those with steel section in-filled with concrete and those with steel encased with concrete.

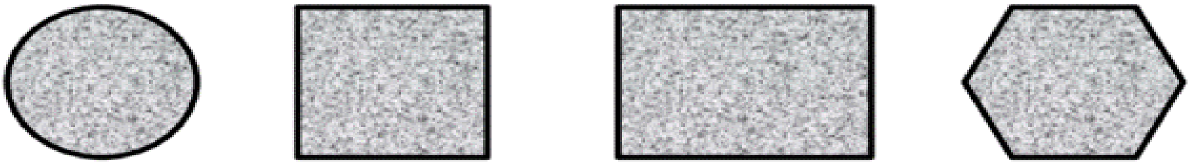

Fig.1.1 Concrete-Filled Steel Tubes Without Reinforcement (1)

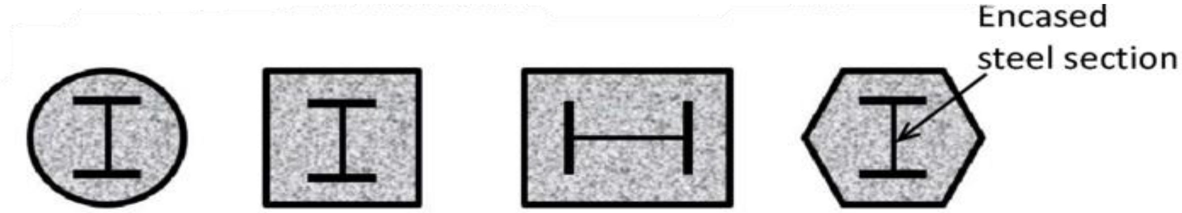

Fig.1.2 Concrete Encased Steel Section (1)

The use of composite columns, encased or in-filled, results in significant reduction of the column size when compared to regular reinforced concrete columns needed to carry the same load. Hence, considerable economic savings can be obtained. Also, the column size reduction is advantageous where floor space required, such as in office blocks and car parking's.

In this paper, the Analytical study was carried out on concentrically and eccentrically loaded circular 4-tube laced CFST columns with the constant length-to-diameter (width) ratio of 8 is used to find the ultimate load carrying capacity with eccentricity at several locations. Further the load v/s deflection graph has been drawn to compare the ultimate load at different location. On the basis of the findings, it was shown that the eccentricity is the one of the main factors that influence the ultimate load capacity of CFST columns.

2. Literature Review

- **Ilanthalir A, Jerlin Regin J, Maheswaran J (2020) [6]: -** This article provides an overview of the axial compression behavior of concrete-filled tubular steel (CFST) columns formed with various cross-sections such as circular, Rectangular, Square, elliptical, Hexagonal, Octagonal and Round-ended. The confinement in the concrete core due to the difference in cross-sectional shape of the steel pipe is also explained.

The results show that circular steel sections provide the strongest confinement compared to rectangular/square, hexagonal, and custom-shaped sections.

The confinement of the square/rectangular steel tube to the core concrete is strongest at the corners than at the center. Hexagonal confinement is in between circular and rectangular.

- **Hasan Abdulhadi Ajel, Abdulnasser M. Abbas (2015) [7]: -** In this article, the load-bearing behavior of concrete-filled steel tubular columns (CFST) was investigated using experimental and analytical studies. The effects of concrete compressive strength, steel pipe thickness, reinforcement and longitudinal reinforcement are taken into account. The tested samples were studied analytically using three-dimensional finite element representation by ANSYS (ver. 12.1) computer program.

  The results show that the deformation of the column (25 MPa) filled with normal concrete is greater than that of the column (60 MPa) filled with high strength concrete. The effect of width-thickness (b/t) and diameter to thickness (d/t) ratio on the ultimate strength of (CFST) columns will have a reverse action, when of (b/t) or (d/t) decreases the caused increasing in peak load capacity of columns which is varied from 4.47 to13.37 % for square samples varied from 8.00 to 12.14 percent for circular sections depending on the type of stiffened, compressive strength of concrete and ratio of (b/t) and (d/t).
- **Nehla Najeeb, Shilpa Sara Kurian (2018)[8]:-**]: In this article, a comparative study of the structural performance of columns made of concrete-filled steel tubes (CFST) and concrete-filled aluminum alloy tubes (CFAT) was carried out. The results show that the measured maximum load capacity of the reinforced CFST and CFAT column

specimens is greater than that of the CFST and CFAT column specimens without reinforcement, and the load carrying capacity for CFAT column specimens with and without stiffeners is almost double than that for CFST column specimens with and without stiffeners.

- **Zhijing Ou ; Baochun Chen, P.E. ; Kai H. Hsieh ; Marvin W. Halling, S.E., F.ASCE ; and Paul J. Barr, M.ASCE(2011)[9]:-** In this article, an experimental and analytical examination of concrete-filled steel tubular (CFST) laced columns is presented. These columns consist of four concrete-filled steel tubes that are laced together. Experimental tests were performed to quantify the column failure mechanism during peak load. Experiments were designed to obtain load-deflection curves. These curves were then used to quantify the load-bearing behavior of each element of the hybrid column.

Experimental results indicate that the compression force of the lateral members dominates the failure mechanism of CFST columns. In-plane bending occurred when member segments reached the compression failure load. The forces in the lacing elements (diagonal and horizontal bracing) were found to be minor and remained in the elastic range through failure. Analytical studies have shown that load-bearing capacity decreases with increasing aspect ratio and eccentricity. In addition, a finite element analysis of four in situ structure-based CFST columns was performed to determine the final load-bearing capacity and compared with multiple building codes.

- **Haiyang Gao; Lianguang Wang; and Ni Zhang (2021)** In this article, fiber-reinforced polymer (FRP) reinforced concrete-steel double-skin tubular columns (DSTCs) consist of an exterior glass FRP tube, an interior steel tube, and reinforced concrete in between.

  This new composite member offers the advantages of high ductility, light-weightiness, resistance to corrosion, and full utilization of building materials. The main considerations were the eccentricity, void ratio, longitudinal reinforcement ratio, and concrete strength.

The results showed that the placement of steel bars within hybrid DSTC can improve the eccentric resistance and ductility of composite columns.

Furthermore, this study showed that the eccentric carrying capacity and initial stiffness reduced as the eccentricity and void ratio increased, whereas it increased with the longitudinal reinforcement ratio and concrete strength.

3. Finite element modelling

Analytical study on thin-walled CFST column model with 4-different eccentricities were performed as listed in table 3.1 for octagonal cross-section and for circular cross-section refer the table 3.2 where the test information of the specimens is shown. In the table, “L” is the length of the column, “ta” is the top endplate thickness of CFST model and the top endplate is rigid for fully loaded specimens, the dimensions of square loading plate which is 600mm*600mm, “e” is the eccentricity. The outside diameter of the steel tubes “D” was 150 mm and the thickness of the octagonal CFST wall “t” was 1.66 mm and for circular c/s 1.8mm, length-to- diameter (width) ratio L/D 8 for both cross-sections, “Nu” is the ultimate load.

The specimen parameters “b”, “d” (shown on Fig. 3.1), represent the transverse dimensions of the specimen, respectively. Variables A1, A2, and A3 are the dimensions of the tubular elements. The first value of each parameter is the out-to-out dimension and the second value is the wall thickness. A1 is the parameter for the longitudinal elements, A2 and A3 are the parameters of the lacing tubes.

For all specimens the following parameters were held constant, b and d are same 488 mm, A1 is Φ89 × 1.66 (mm), A2 is Φ48 × 1.5 (mm), and fy is 400 MPa. Parameters that varied are shown in table 3.1 and table 3.2, the shear connectors are provided of dimensions of 15mm*30mm as shown in fig. no. 3.4.

The analytical study was performed to investigate the influence of the following parameters on the behavior of CFST columns subjected to concentrically and eccentrically loaded specimen: (1) sectional type: - octagonal and circular c/s with stud bolts; (2) 4-eccentricities at different locations; (3) shear connectors.

3.1 Table: Characteristic of octagonal CFST

Specimen	L(mm)	A3	Fy	Fck (Mpa)	e (mm)	L/D	Nu (KN)
E0	1200	48ϕ*1.5	400	30	300	8	2832
E1	1200	48ϕ*1.5	400	30	350	8	2812
E2	1200	48ϕ*1.5	400	30	400	8	2542
E3	1200	48ϕ*1.5	400	30	500	8	1702

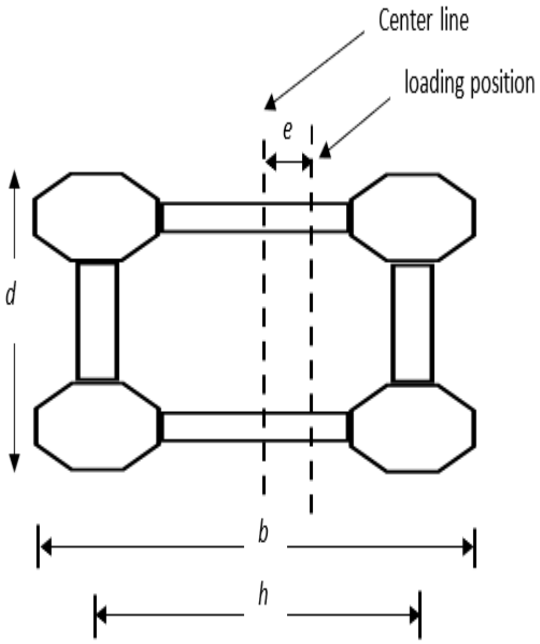

Fig.3.1: Analytical model setup details

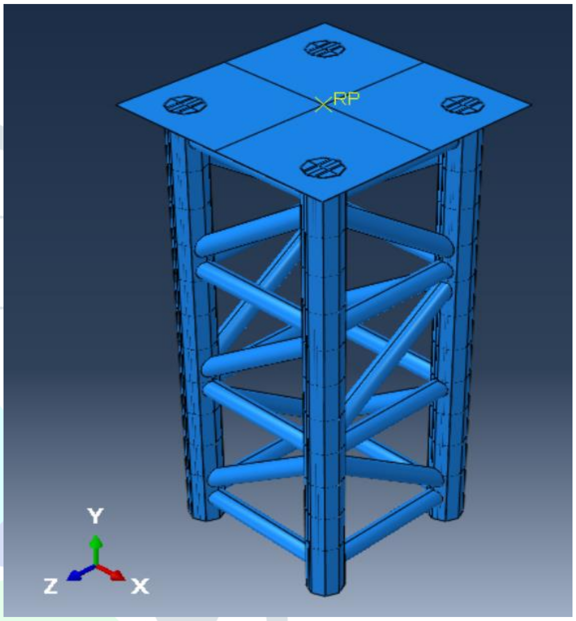

Fig3.2: FEA model of octagonal 4-Laced CFST with shear connectors

3.2 Table: Characteristic of octagonal CFST

Specimen	L(mm)	A3	Fy	Fck (Mpa)	e (mm)	L/D	Nu (KN)
E0	1200	48ϕ*1.5	400	30	300	8	2675
E1	1200	48ϕ*1.5	400	30	350	8	2651
E2	1200	48ϕ*1.5	400	30	400	8	2371
E3	1200	48ϕ*1.5	400	30	500	8	1563

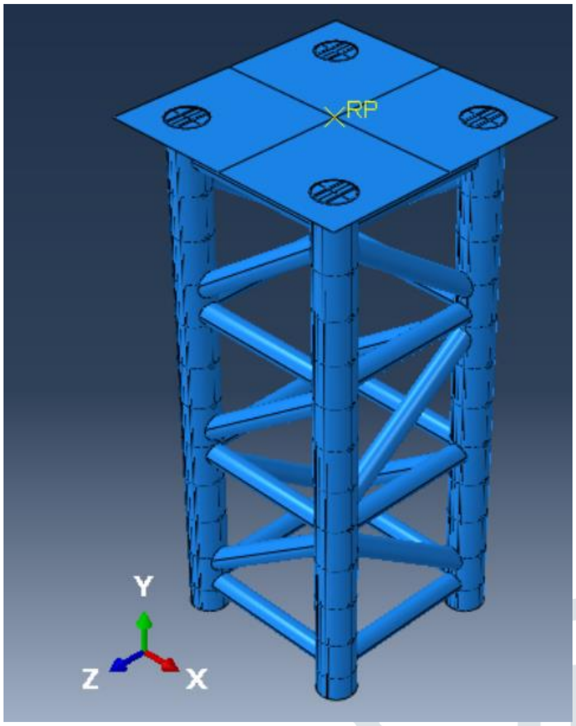

Fig3.3: FEA model of circular 4-Laced CFST with shear connectors

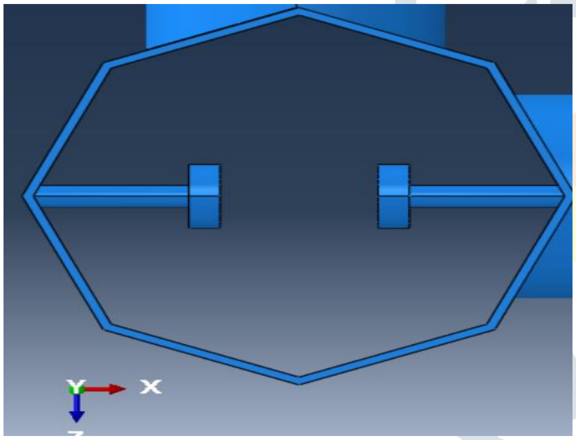

Fig.3.4: FEA model with Shear connectors

The tubes were modeled from mild steel plate, and a rigid steel plate was welded to each tube as the top a bottom endplate. The average yield strength (f_y), tensile strength and modulus of elasticity of the steel were found to be 230 MPa, 410 MPa and 210000 N/mm2 and the average Poisson ratio was 0.281 respectively.

A standard of concrete was filled into the steel tubes. The measured average value of concrete compressive cube strength (fcu) and modulus of elasticity were 30 MPa and 26600 N/mm2 at 28 days, respectively.

A 'reference point' (fig.3.3) on the top surface of the loading plate was set to model on the top platen of the testing machine, and the boundary conditions for the reference point were 'pinned' at top and fixed at bottom shown in Fig. 4.1, i.e., at top the translation components of reference point were restricted and the rotations of reference point were set free and at bottom the translation and rotational components were restricted. The boundary conditions adopted are illustrated in Fig. 4.1. The top surface of the loading plate had the same translation and rotation components as those of the reference point. A uniform axial deformation (D) was applied to the rigid plate of the composite columns. The deformations were applied at variable amplitude, and the responses of concentrically loaded CFST columns after each step could be calculated from the equilibrium equations.

4. Finite element analysis (FEA)

To analyze the load versus deformation relation and mechanism of CFST columns subjected to concentrically and eccentrically compression with L/D ratio 8, a dynamic explicit quasi-static 3-D nonlinear finite element analysis (FEA) model was developed using ABAQUS software [5] for 0.2sec of time period.

4.1 Model overview

4.1.1 Parts of FE Modelling

In the modelling the steel tube, concrete core, loading plate, horizontal and inclined bracings has been done and the respective assembly is shown in fig 4.1, the element types for the steel tube, core concrete, endplate and the contact interactions between steel and concrete, are the same as the results presented in [2, 3 & 4].

A element type C3D8R: An 8-node linear brick were selected for both cross-sections of the longitudinal steel tubes and circular lacing tubes, whereas solid bar elements were chosen for the concrete core and The Loading plate was made shell 3D discrete rigid.

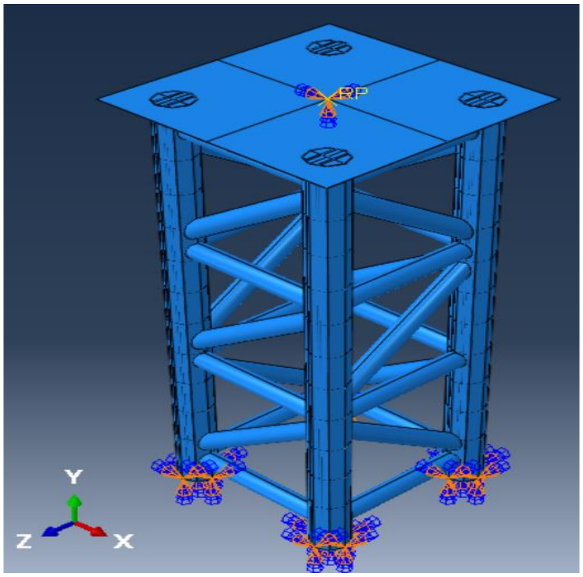

Fig.4.1: FEA model with BC's and RP

4.1.2 Load conditions

The concentric and eccentric displacement applied on the CFST columns at reference point (shown in fig 4.1) at a gradually increasing displacement control load is mainly taken by the strong axial direction; therefore, the 3-D finite-element model only considers the two axial columns and the connected lacing tubes in the strong direction.

4.1.3 Support conditions

Column supports were modeled at the base with a fixed. Elastic material properties (i.e., elastic modulus of fe410 steel 2.1*10E5 Mpa poisons ratio .28, Density 7.85E-09), for concrete m30 grade density 2.5E-09, young's modulus 26600 poisons ratio .2 and same properties apply for shear connectors were assigned to the respective elements. The modeled columns were loaded incrementally up though failure of the structure.

4.1.4 Meshing and contact properties

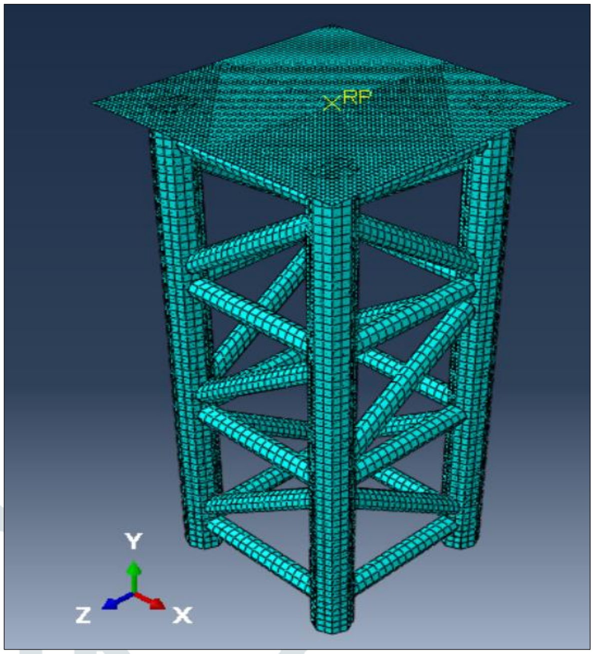

Fig.4.2: Meshing of FEA model

To increase the accuracy of results partitioning was done at every interval of 20mm each part of assembly with the fine meshing.

Position constraints were utilized to assemble the whole model. For the simulation of the interface between steel tube and concrete core, the contact properties used are normal contact behavior, the default option for ''Constraint enforcement method'' was considered and the ''Hard'' contact option was used. For tangential contact behavior, the friction between steel plate and concrete core was considered as 0.5. Tie constraints are used to tie the shear connectors to the steel tube and loading rigid plate to steel tube for the duration of a simulation.

5. Results and conclusion

The analytical results from ABAQUS were used to predict the behavior for octagonal and circular cross-sectional of 4-tube laced CFST column with different eccentricity and several results were drawn.

5.1 Table: Load V/S Displacement for octagonal c/s

Dis	load e500	load e400	load e350	load e300
0	0	0	0	0
5	890703	1.32E+06	1.63E+06	1.73E+06
10	1.06E+06	1.61E+06	1.94E+06	2.00E+06
15	1.17E+06	1.79E+06	2.11E+06	2.19E+06
20	1.28E+06	1.96E+06	2.26E+06	2.32E+06
25	1.37E+06	2.08E+06	2.38E+06	2.43E+06
30	1.44E+06	2.19E+06	2.48E+06	2.52E+06
35	1.52E+06	2.28E+06	2.57E+06	2.60E+06
40	1.58E+06	2.37E+06	2.65E+06	2.67E+06
45	1.64E+06	2.46E+06	2.74E+06	2.75E+06
50	1.70E+06	2.54E+06	2.81E+06	2.83E+06

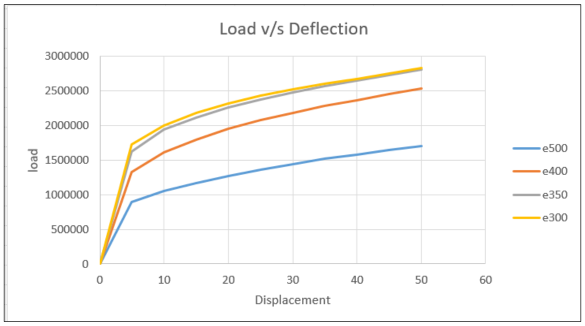

Fig.5.1: Load V/S Deflection curves at different eccentricities for octagonal c/s

5.2 Table: Load V/S Displacement for circular c/s

Dis	load e500	load e400	load e350	load e300
0	0	0	0	0
5	990703	1424870	1727560	1825550
10	1.17E+06	1.72E+06	2.05E+06	2.11E+06
15	1.29E+06	1.91E+06	2.23E+06	2.31E+06
20	1.41E+06	2.09E+06	2.39E+06	2.45E+06
25	1.51E+06	2.22E+06	2.52E+06	2.57E+06
30	1.59E+06	2.34E+06	2.63E+06	2.67E+06
35	1.68E+06	2.44E+06	2.73E+06	2.76E+06
40	1.75E+06	2.54E+06	2.82E+06	2.84E+06
45	1.82E+06	2.64E+06	2.92E+06	2.93E+06
50	1.89E+06	2.73E+06	3.00E+06	3.02E+06

The behaviors of CFST columns under concentrically and eccentrically compression with L/D of 8 predicted by the FEA model are compared. Fig.5.1-5.3 Demonstrates a comparison between the ultimate loads with different eccentricities of the tested specimens. It can be seen that, in general, the ultimate load decreases with increase in eccentricity.

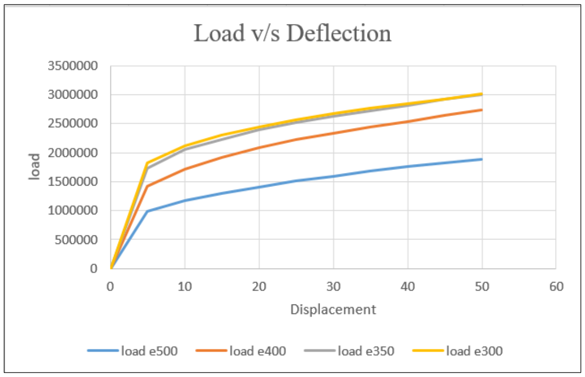

Fig.5.2: Load V/S Deflection curves at different eccentricities for circular c/s

The above graphs shows that with the increasing eccentricity the load bearing capacity of specimen is decreased.

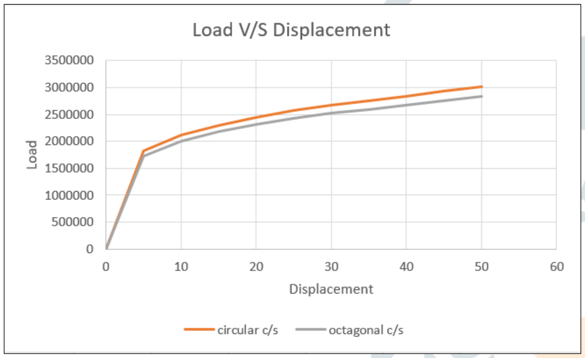

Fig.5.3: figure shows the difference for Load V/S Deflection curves at different eccentricities for octagonal and circular c/s

The difference of ultimate load at zero eccentricity for circular and octagonal cross-section were found to be 1.90E+05 N and the difference between ultimate load of Eccentricity 200 and the zero eccentricity is 1.13E+06 N for octagonal cross-section. The difference between the ultimate load for circular 4-tube laced CFST with shear connectors and circular 4-tube laced CFST without shear connectors found to be 1.28E+06 N. The difference between the ultimate load for octagonal 4-tube laced CFST with shear connectors and circular 4-tube laced CFST without shear connectors found to be 1.09E+06 N. The results of circular 4-tube laced CFST are taken from Zhijing Ou (9).

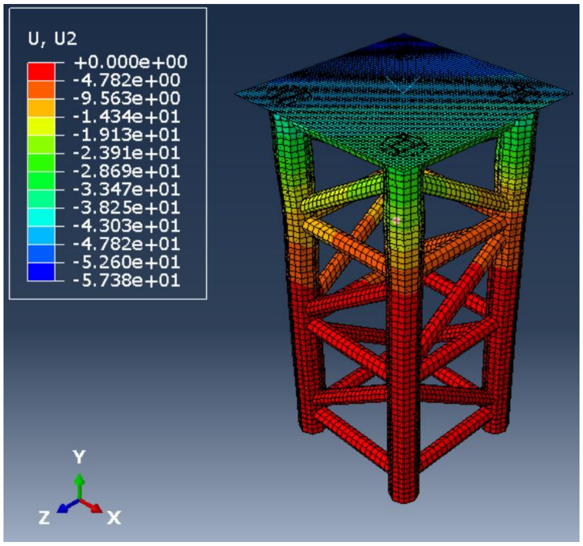

Fig.5.4: Deflection of Octagonal 4-tube laced CFST in U2 direction

The maximum deflection occurs in the octagonal 4-tube laced CFST column is 57.4mm as shown in fig 5.4

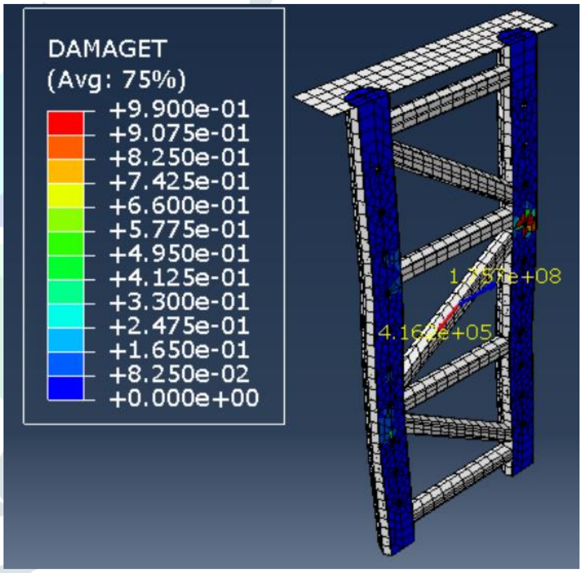

Fig.5.5 Specimen showing tensile damage of concrete.

Fig. 5.5 shows the tensile damage of 4-tube laced CFST for octagonal cross-section and the Fracture due to severe buckling initiated at the longitudinal column and propagated across the model. Finally, the specimens lost their capacity to maintain the axial load and suffered a complete failure identified in the numerical analysis.

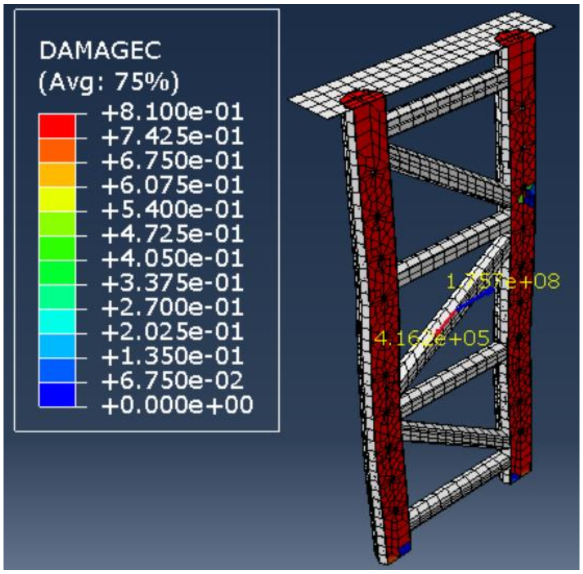

Fig.5.6. model showing Damage of concrete

Fig.5.6 shows the damage of concrete for the eccentricity of 200mm for octagonal 4-tube laced CFST.

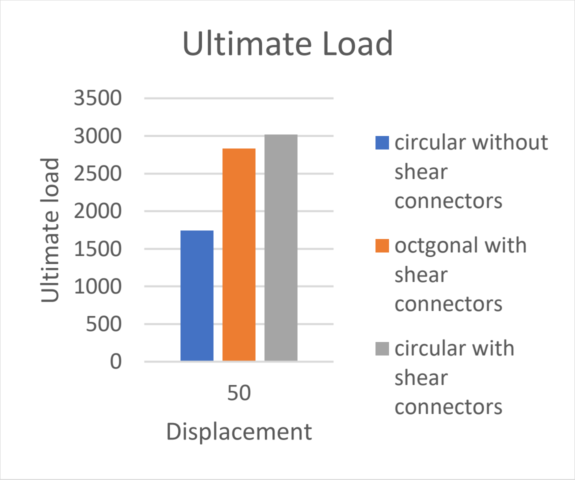

Fig. 5.7 ultimate load at 50mm displacement

The ultimate load at 50mm of 4-tube laced CFST without shear connectors is 1740 KN, 2831KN for the circular cross-section with shear connectors and the 3021 KN for the circular cross-section with shear connectors.

6. Conclusion

Numerical study on behavior of 4-tube laced CFST composite column for octagonal and circular cross-sections was studied using finite element software Abaqus CAE. Axial load carrying capacity V/S deformation of 4-tube laced columns with shear connectors for different c/s with different eccentricities were studied. The main conclusions are listed as follows:

1. The axial load carrying capacity of 4-tube laced CFST Composite columns for both the cross-sections was decreased as the eccentricity increased for L/D ratio 8.
2. The load carrying capacity of circular CFST with shear connectors is 6.71% more than octagonal CFST with shear connectors.
3. The ultimate load capacity of Circular with shear connectors is 32.2% more than the circular CFST without shear connectors.
4. The ultimate load capacity of octagonal with shear connectors is 26.7% more than the circular CFST without shear connectors.

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