International Journal of Scientific & Engineering Research Volume 10, Issue 5, May-2019
ISSN 2229-5518

Performance of Special Shaped Columns Composed of Concrete Filled Steel Tube Monocolumns

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Abstract— This paper presents the review of various studies conducted on the performance of special shaped columns composed of concrete filled steel tube monocolumns under different loading conditions. The failure modes, load-deformation relationship and strain distribution of the columns were studied. Axial load, eccentric and lateral loads were applied on these CFST columns and its load carrying capacities were compared for different parametric changes. Parametric studies include change in monocolumn shape and replacement of vertical steel plates with lacing bars. The main cause of failure on these types of columns was due to loacal buckling. Analysis of these models was done using ansys software. Various studies conducted on these special shaped CFST columns were discussed in this paper.

Index Terms— ANSYS software, Axial load, Eccentric load, Lacing bars, Lateral load, Load carrying capacity, Local buckling, Monocolumns, Special shaped columns composed of concrete filled steel tube monocolumn.

1 Introduction

The special shaped CFST columns are becoming increasingly attractive solution to engineering design. Concrete filled steel tubular columns have been commonly used in numerous enginnering structures due to their excellent composite actions between the steel tube and concrete infill. Structural system consisting of special shaped columns constitutes a new approach that has developed in recent years. The main benefit of this type of columns is its ability to be embedded into walls, allowing columns to be placed without intruding on the usable space of a building, providing greater flexibility for architectural design.

There are mainly three types of special shaped concrete filled steel tube columns: concrete filled special shaped steel tubular columns, multiple cell special shaped CFST columns and special shaped columns fabricated with concrete filled steel tube monocolumns. The concrete filled special shaped steel tubular columns are generally formed by filling single, special shaped section steel tube with concrete. The main disadvantage of this type column is that the confinement effect of the steel tube wall on the core concrete is negligible due to thin walls of the section. In case of torsional and lateral deformation the concrete and steel tube can be easily separated, which is detrimental to the strength of the core concrete. The multiple cell special shaped CFST columns is formed by welding three rectangular tubes and then concrete is poured vertically into the steel tubes.

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The overall performance of this column system is determined by the capacity of the vertical weld. But the welding residual stress is complicated at the connected parts and the welding stress cannot be ensured. The local buckling of the steel tube is restrained and the confinement effect on the core concrete is considerable.

Finally the special shaped columns fabricated with concrete filled steel tube monocolumns are formed by connecting monocolumns with lacing bars or steel plates. The columns have satisfactory mechanical properties and seismic behavior.

Special shaped columns fabricated with concrete filled steel tubes monocolumns can be made in different shapes like L shape, T shaped and crisscross shape. Among these shapes special columns with T shape in used for further investigation. Hence in this study, three type of innovative T shaped columns fabricated using CFST connected via double vertical steel plates and lacing bars were proposed and tested under axial load, eccentric load and lateral loads.

Finite element analysis (FEA) has became invaluable part of most structural studies, since it can be used as efficient tool to investigate the structural behavior, especially the composite action between components of CFST specimen. In this work ANSYS software is used for the finite element analysis of the specimens.

2 Literature Review

The Studies on special shaped CFST columns were started by Ting Zhou, Yumeng Jia, Minying Xu, Wang and Chen at the University of Tianjin (2015). The main objectives of their study were to investigate experimental study on the behavior of specially shaped columns composed of concrete filled steel tube frames subjected to constant axial and cyclically varying flexural loading conditions. Three specimens with two storeys and a single span were tested. The research results indicated that the specimens show better ductility and energy dissipation ability.

International Journal of Scientific & Engineering Research Volume 10, Issue 5, May-2019
ISSN 2229-5518

Following this work, another study was conducted by Xiong, Chen, Jingfu Kang, Zhou and Zhang (2017). In that work experimental and finite element study on seismic performance of the special shaped columns composed of concrete filled steel tube monocolumns connected by double vertical steel plates were proposed. The research result shows that the failure of all specimens was due to loacal buckling and was located at the bottom position of side monocolumns. Also the seismic performance of the specimens improved significantly with larger monocolumn cross section size.

Qingoing Xiong, Zhihua Chen, Wang Zhang, Yangsheg Du, Ting Zhou and Jingfu Kang (2017) studied on compressive behavior and design of L shaped columns fabricated using concrete filled steel tubes and concluded that the stability and deformation resistance was improved with this type of special columns. Concrtete infilling between the vertical steel plates helps in reducing the deformation of the plates and delaying local buckling.

Wang Zhang, Zhihua Chen and Qingoing Xiong (2018) conducted a study on performance of L shaped columns comprising concrete filled steel tubes under axial compression and found out that the concrete confinement of the steel tubegot enhanced. The columns show high bearing capacity and ductility. The bearing capacity of the columns increases proportionally with the thicknes of the vertical steel plates.

3 Models

Special shaped columns fabricated with concrete filled steel tube monocolumn can be made in different shapes like L shape, T shape and crisscross shape. Among these shapes special columns with T shapes is used for investigation. Hence in this study, three types of innovative T shaped columns fabricated using CFST connected via double vertical plates and lacing bars were proposed and tested under axial load, eccentric load and lateral loads.

3.1 Finite Element Analysis

The finite element method (FEM) has become a staple for predicting and simulating the physical behaviour of complex engineering systems. The commercial finite element analysis (FEA) programs have gained common acceptance among engineers in industry and researchers. The Finite Element Analysis is a numerical technique in which all complexities of the problems varying shape, boundary conditions and loads are maintained as they are but the solutions obtained are approximate. Solutions can be obtained for all problems by Finite Element Analysis.

3.2 Finite Element Modelling

ANSYS is general purpose finite element software for numerically solving a wide variety of structural engineering problems. The ANSYS element library consists of more than 100 different types of elements. ANSYS Workbench 16.1 is used for the finite element modeling and analysis. Modeling the finite element model is the descritization of model into elements. The goal of meshing in ANSYS Workbench is to provide robust, easy to use meshing tools that will simplify the mesh generation process. The element used in the modeling was SOLID 186 for steel and SOLID 95 for concrete. Here the columns were made with four monocolumns of dimension 100x100x6mm connected with lacing bars of vertical plates of length 150mm and thickness of 4mm. Fig.1 below shows the top view first model of T shaped concrete filled steel tubular column connected with double vertical plates. Fig.2 below shows the top view of second model of T shaped concrete filled steel tubular column connected with lacing bars and Fig.3 below shows the top view of third model of T shaped concrete filled steel tubular column connected with closed lacing bars.

Fig.1. T Shaped CFST column connected with double vertical plates (Top view)

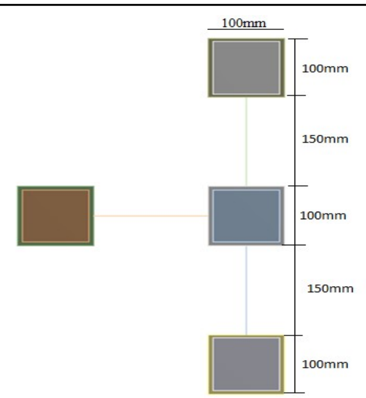
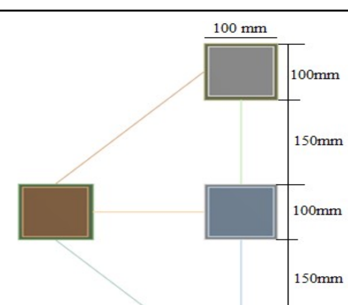


Fig.2. T Shaped CFST column connected with lacing bars (Top view)



3.3 Material Properties

The material model for both steel and concrerte component was assumed to be characterized by isotropic hardening. Elastic properties were defined considering the Young's Modulus equal to 28460Mpa for concrete and in case of steel, $2.01 x 10^5$ for monocolumn and $1.76 x 10^5$ for steel vertical plates. The poisson ratio 0.15 was provided for concrete wheras 0.3 was provided for steel components. Frictional contact was given in concrete steel interface with coefficient of friction equals to 0.2. Fig.4, 5 and 6 below shows the meshed isometric views of T shaped concrete filled steel tube monocolumns connected with double vertical steel plates, lacing bars and closed lacing bars respectively. In case of boundary conditions, the top surface of the specimens were constrained against displacement along the directions X and Z whereas the bottom surface were constained against displacement along the three X, Y and Zdirctions.

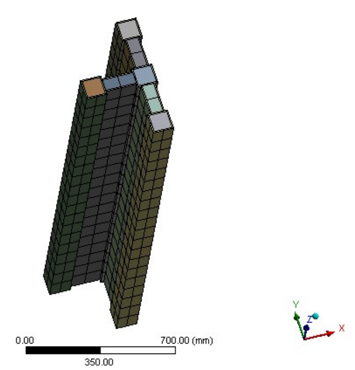


Fig.4. Isometric view of T Shaped CFST column connected with double vertical plates (meshed model)

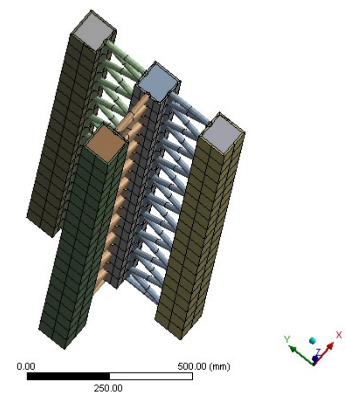


Fig.5. Isometric view of T Shaped CFST column connected with lacing bars (meshed model)

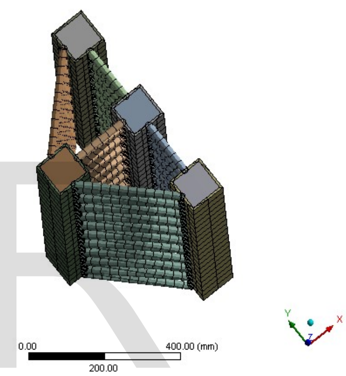


Fig.6. Isometric view of T Shaped CFST column connected with closed lacing bars (meshed model)

4 Result and Analysis

The each model was analysied under with different loading conditions like axial, lateral and eccentric loading. Displacement controlled load was provided for this purpose.

4.1 Axial Loading Condition

Dispalcement controlled load of 30mm was applied axialy at the top surface of centre monocolumn of the specimens and the total deformation with respect to the load was analysed. Fig.7 and 8 below shows the loading condition and total deformation of the T shaped CFST column with double vertical steel plates. In this case the maximum load carrying capacity was obtained as 4533kN with a deformation of 35.135mm.

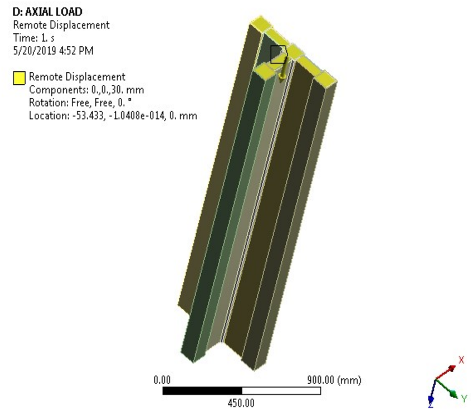


Fig.7. FE model for T shaped CFST column with double vertical plates under axial loading.

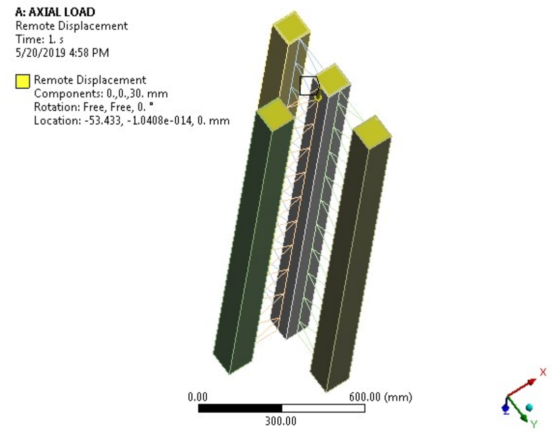


Fig.9. FE model for T shaped CFST column with lacing bars under axial loading.

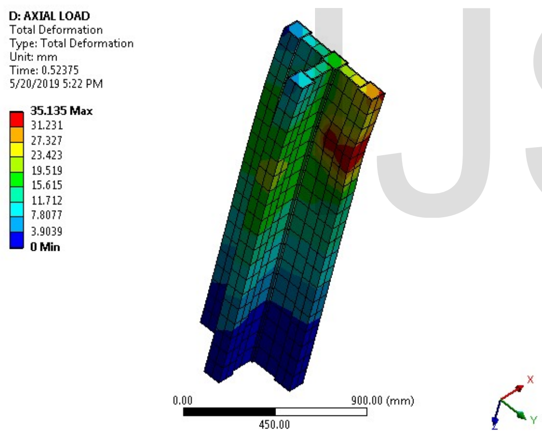


Fig.8. Total deformation for T shaped CFST column with double vertical plates under axial loading.

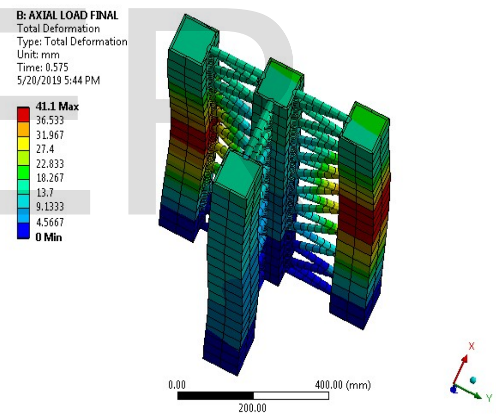


Fig.10. Total deformation for T shaped CFST column with lacing bars under axial loading.

Fig.9 and 10 below shows the loading condition and the total deformation of the T shaped CFST columns connected with lacing bars under displacement controlled load of 30mm. Here the maximum load carriying capacity of the specimen was observed with a value of 4383kN with a maximum displacement of 41.1mm. The stress was mainly observed at the side monocolumns later extendend to the lacing bars.

Fig.11 and 12 below shows the loading condition and the total deformation of the T shaped CFST columns connected with closed lacing bars under displacement controlled load of 30mm. Here the maximum load carriying capacity of the specimen was observed with a value of 5277kN with a maximum displacement of 40.396mm. The stress was mainly observed at the side monocolumns later extendend to the lacing bars.

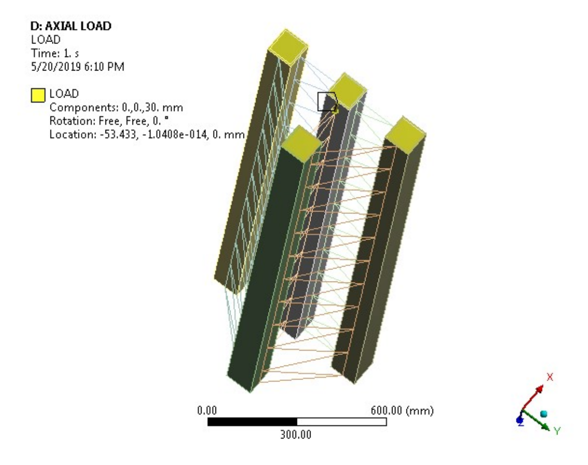


Fig.11. FE model for T shaped CFST column with closed lacing bars under axial loading.

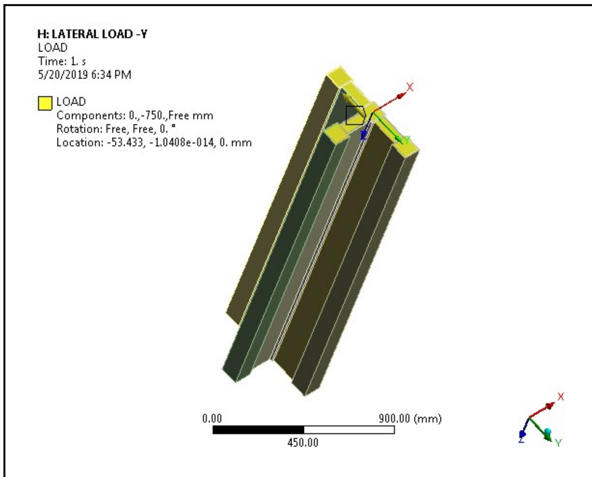


Fig.13. FE model for T shaped CFST column with double vertical steel plates under lateral loading.

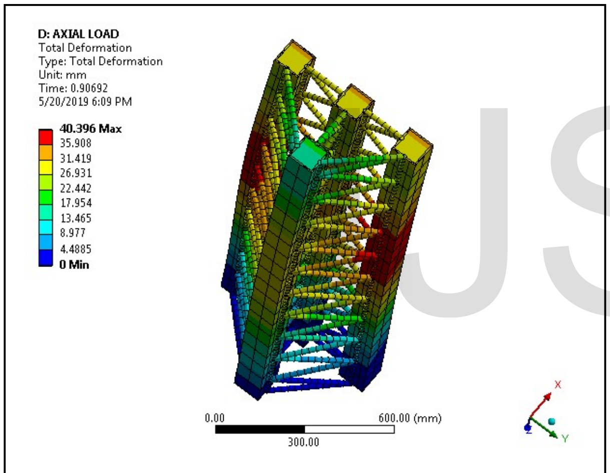


Fig.12. Total deformation for T shaped CFST column with closed lacing bars under axial loading.

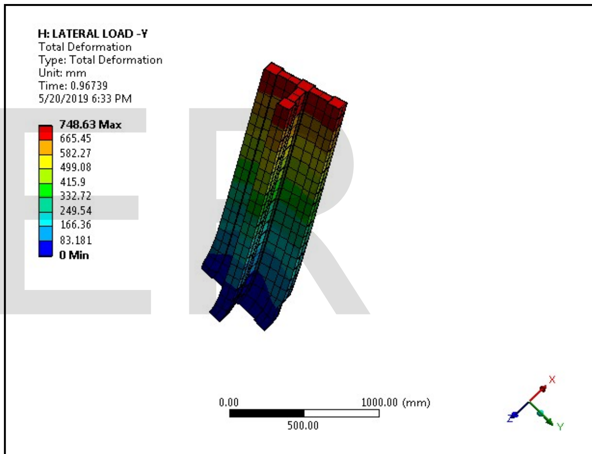


Fig.14. Total deformation for T shaped CFST column with double vertical steel plates under lateral loading.

4.2 Lateral Loading Condition

Dispalcement controlled load of 750mm was applied laterally at the top surface of centre monocolumn of the specimens and the total deformation with respect to the load was analysed. Fig.13 and 14 below shows the loading condition and total deformation of the T shaped CFST column with double vertical steel plates. In this case the maximum load carrying capacity was obtained as 411.2kN with a deformation of 748.63mm. The stress was greatly focused at the top surface of the specimen and alocal buckling failure was observed at the bottom surface of the column.

Fig.15 and 16 below shows the loading condition and the total deformation of the T shaped CFST columns connected with lacing bars under laterally applied displacement controlled load of 750mm. Here the maximum load carriying capacity of the specimen was observed with a value of 374.67kN with a maximum displacement of 121.47mm. The stress was mainly observed at the top surface of the specimen and failure mode of local buckling was generated at the support region in the column.

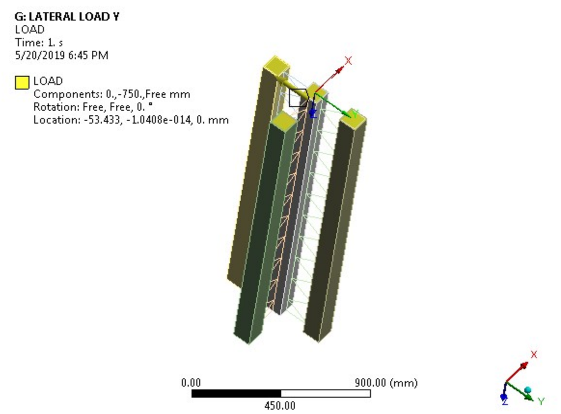


Fig.15. FE model for T shaped CFST column with lacing bars under lateral loading.

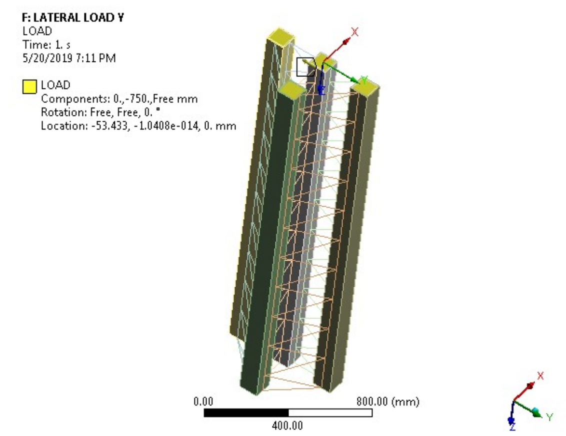


Fig.17. FE model for T shaped CFST column with closed lacing bars under lateral loading.

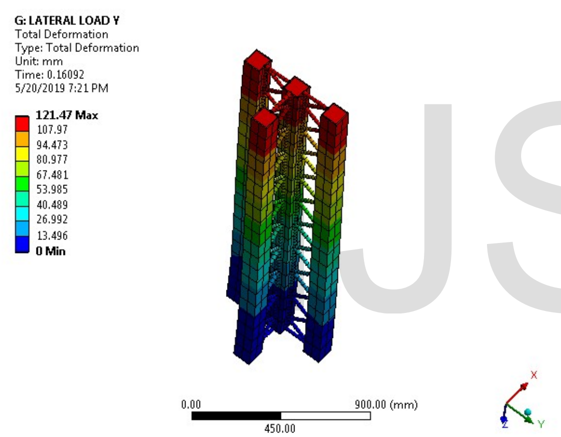


Fig.16. Total deformation for T shaped CFST column with lacing bars under lateral loading.

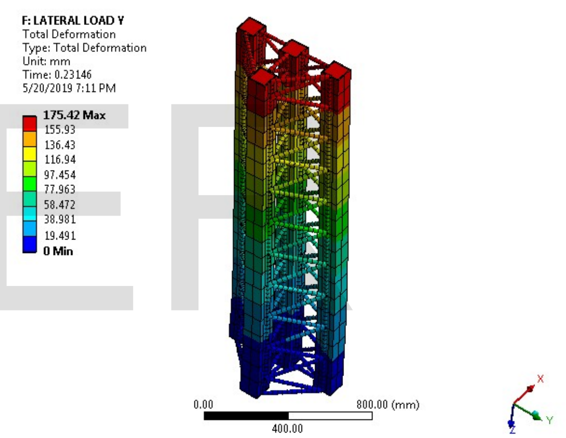


Fig.18. Total deformation for T shaped CFST column with closed lacing bars under lateral loading.

Fig.17 and 18 below shows the loading condition and the total deformation of the T shaped CFST columns connected with closed lacing bars under laterally applied displacement controlled load of 750mm. Here the maximum load carriying capacity of the specimen was observed with a value of 445kN with a maximum displacement of 175.42mm. The stress was mainly observed at the top surface of the specimen.

4.3 Eccentric Loading Condition

Dispalcement controlled load of 30mm was applied with an eccentricity of 25%, 50% and 75% of length from the centre of monocolumn at the top surface of the specimens and the total deformation with respect to the load was analysed. Fig.19 below shows the loading condition of the column. Fig.19. a, b and c shows the total deformation of the T shaped CFST column with double vertical steel plates according to the application of eccentric load at a distance of 25%, 50% and 75% of length from the centre of monocolumn respectively.

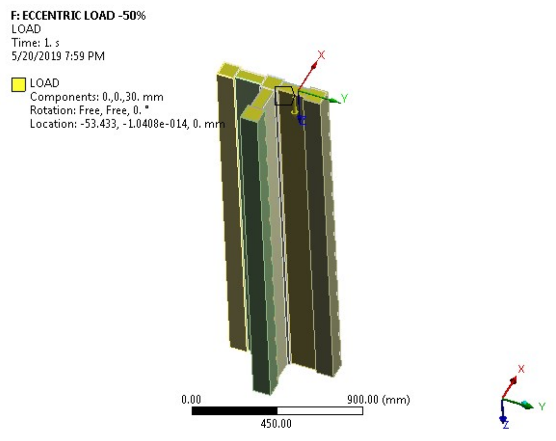


Fig.19. FE model for T shaped CFST column with double vertical steel plates under different eccentric loading.

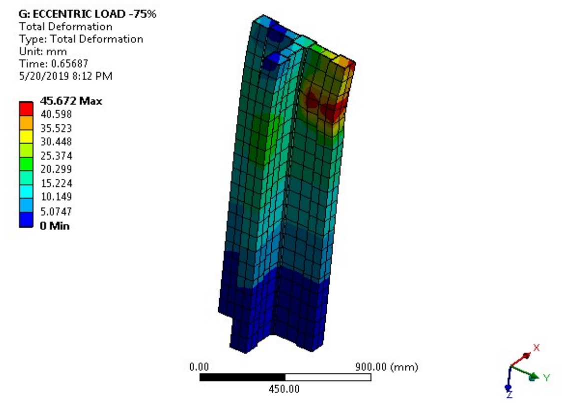


Fig.19.c. Total deformation for T shaped CFST column with double vertical steel plates under under eccentric load at 75% of length from the centre monocolumn.

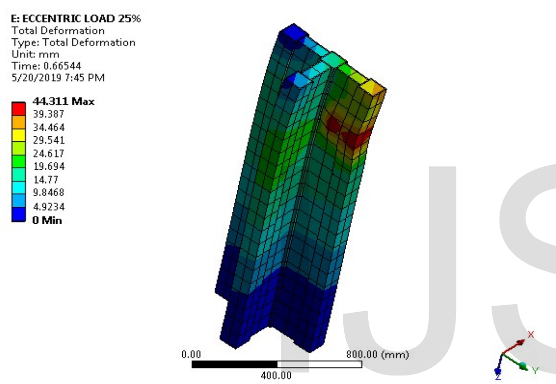


Fig.19.a. Total deformation for T shaped CFST column with double vertical steel plates under eccentric load at 25% of length from the centre monocolumn.

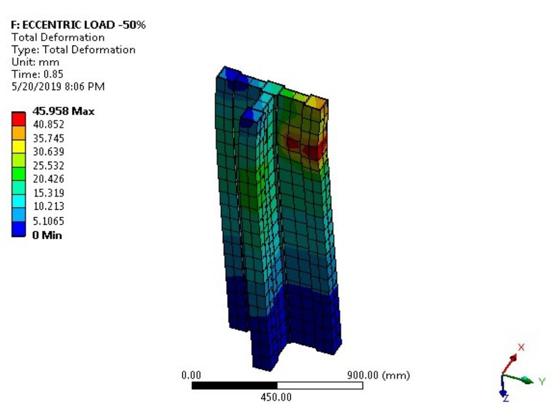


Fig.19.b. Total deformation for T shaped CFST column with double vertical steel plates under eccentric load at 50% of length from the centre monocolumn.

Fig.20 below shows the eccentrically applied load for T shaped CFST column connected via lacing bars with a magnitude of 30mm displacement. Fig.20. a, b and c denotes the total deformation of those columns when eccentric load was applied at a percentage of 25%, 50% and 75% towards the length of the column from the centre of monocolumns. The result shows that in case of eccentrically applied load at 25% of length, the maximum load was obtained as 3323.8kN with a displacement of 52.525mm. Whereas for columns with 50% and 75%of eccentric loading the maximum load carrying capacity and deformation was 3022.1kN, 2488kN, 33.16mm and 30.516mmrespectively.

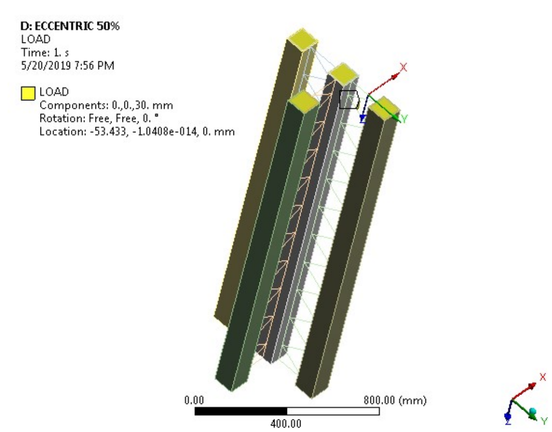


Fig.20. FE model for T shaped CFST column with lacing bars under eccentric loading of different percentages.

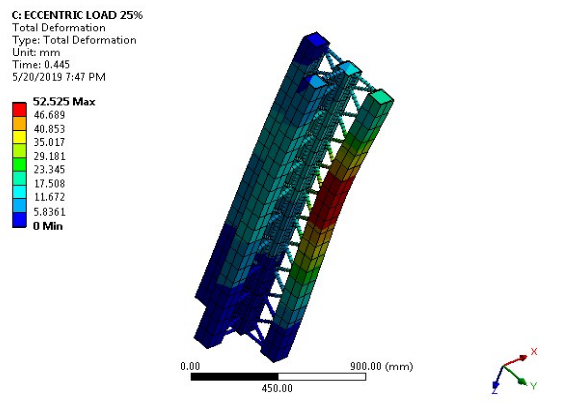


Fig.20.a. Total deformation for T shaped CFST column with lacing bars under eccentric load at 25% of length from the centre monocolumn.

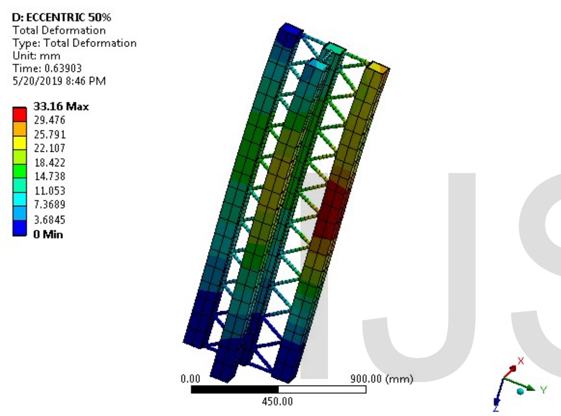


Fig.20.b. Total deformation for T shaped CFST column with lacing bars under eccentric load at 50% of length from the centre monocolumn.

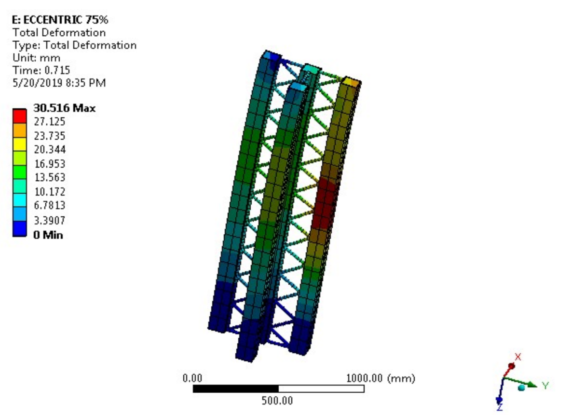


Fig.20.c. Total deformation for T shaped CFST column with lacing bars under eccentric load at 75% of length from the centre monocolumn.

Fig.21 below shows the eccentrically applied load for T shaped CFST column connected via closed lacing bars with a magnitude of 30mm displacement. Fig.21. a, b and c denotes the total deformation of those columns when eccentric load was applied at a percentage of 25%, 50% and 75% towards the length of the column from the centre of monocolumns. The result shows that in case of eccentrically applied load at 25% of length, the maximum load was obtained as 4520kN with a displacement of 42.60mm. Whereas for columns with 50% and 75%of eccentric loading the maximum load carrying capacity and deformation was 3672kN, 3006kN, 41.92mm and 35.84mmrespectively.

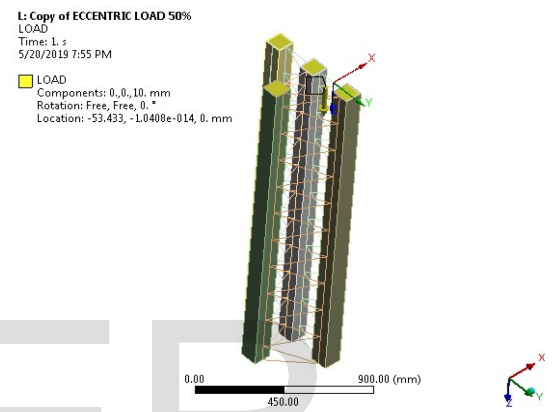


Fig.21. FE model for T shaped CFST column with closed lacing bars under eccentric loading of different percentages.

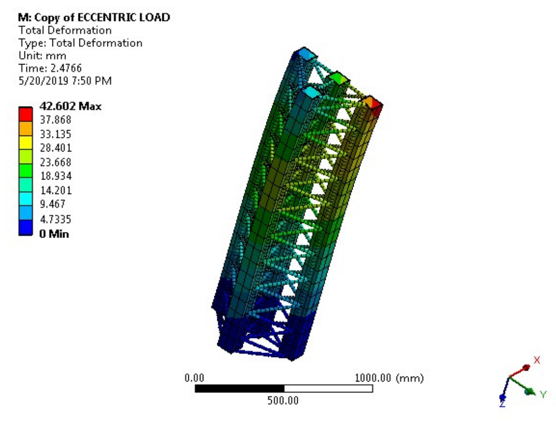
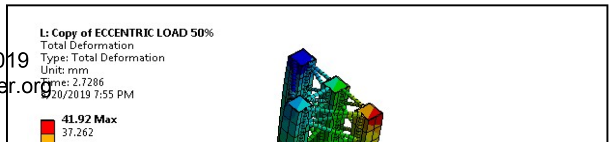


Fig.21.a. Total deformation for T shaped CFST column with closed lacing bars under eccentric load at 25% of length from the centre monocolumn.



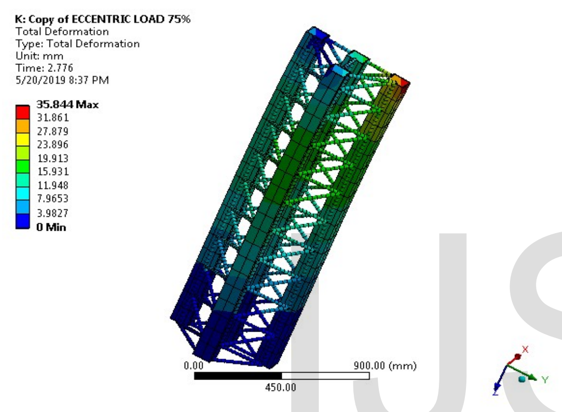


Fig.21.c. Total deformation for T shaped CFST column with closed lacing bars under eccentric load at 75% of length from the centre monocolumn.

5 Comparison of Analysis Result

Chart.1. below shows the comparative study of T shaped CFST columns connected by double vertical plates, lacing bars and closed lacing under the condition of axial loading. When comparing the T shaped CFST column connected by lacing bars with respect to T shaped CFST column connected via double vertical steel plates, the load carriying capacity was reduced by a percentage value of 3.31%but in case of T shaped CFST column connected by closed lacing bars, the load carriying capacity was increased by a percentage value of 16.41%. So that it can concluded that in case of axial loading the T shaped CFST columns connected with closed lacing bars shows a better result.

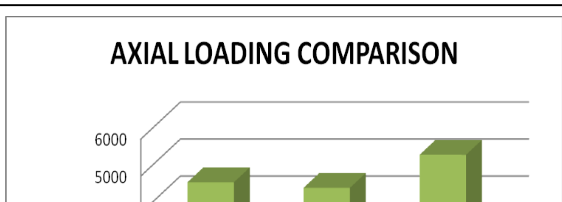


Chart.2. below shows the comparative study of T shaped CFST columns connected by double vertical plates, lacing bars and closed lacing under the condition of lateral loading. When comparing the T shaped CFST column connected by lacing bars with respect to T shaped CFST column connected via double vertical steel plates, the load carriying capacity was reduced by a percentage value of 8.88%but in case of T shaped CFST column connected by closed lacing bars, the load carrying capacity was increased by a percentage value of 8.27%. So that it can concluded that in this case also the T shaped CFST columns connected with closed lacing bars shows a better value on lateral loading.

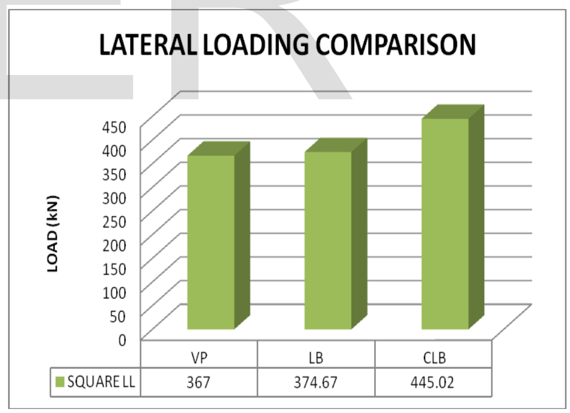


Chart.2. Comparison of lateral load for T shaped CFST column connected with double vertical plates, lacing bars and closed lacing bars.

Chart.3, 4 and 5 belowdenotes the comparative study of T shaped CFST columns connected by double vertical plates, lacing bars and closed lacing under the different conditions of eccentric loading. In case of 25% of eccentric loading, the lacing bars shows a reduction in the load carriying capacity by a percentage value of 2.24% whereas the column with closed lacing bars increased by a percentage of 32.94%. In case of eccentric loading of 50% and 75%, both the columns with lacing bars and closed lacing increased the load carrying capcity by 14.78%, 39.46%,16.76% and 41.073% respectively.

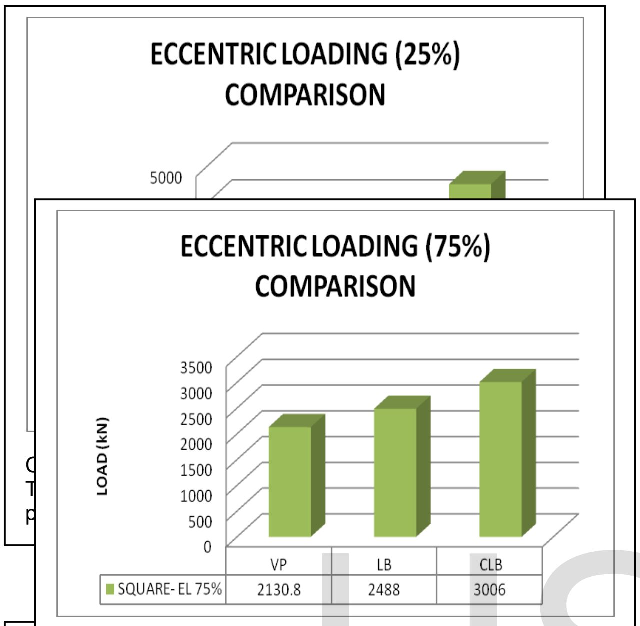


Chart.5. Comparison of eccentric load at 75% of length for T shaped CFST column connected with double vertical plates, lacing bars and closed lacing bars.

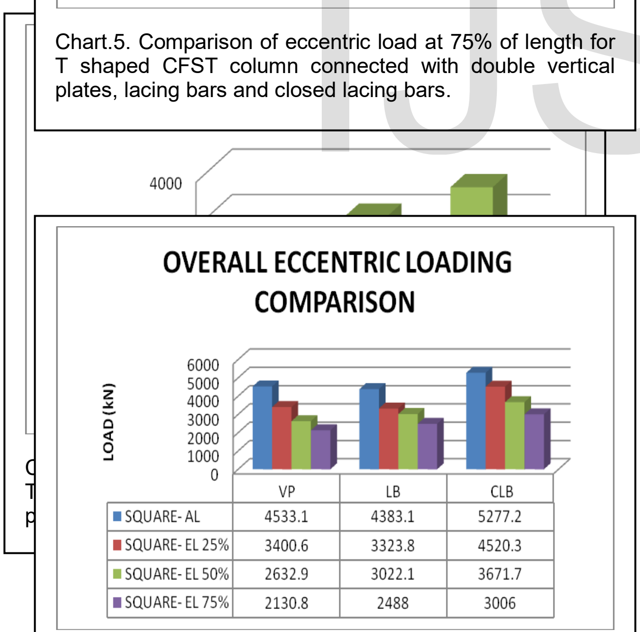


Chart.6. Comparison of overall eccentric load for T shaped CFST column connected with double vertical plates, lacing bars and closed lacing bars.

6 Conclusion

Based on the study on performance of special shaped concrete filled steel tubular column connected via double vertical plates, lacing bars and closed lacing bars under different loading conditions, the following conclusions can be drawn:

1. The performance of special shaped CFST column was better than normal CFST column. Since special shaped CFST columns provide a better ductility and seismic performance when compared with normal CFST column.
2. Apart from normal CFST columns, special shaped CFST columns can be embedded into walls which help to avoid column protrusion and thus indoor space can be increased.
3. From the study on different loading conditions all the columns behaved in a same way of failure on application of load on the top surface. Local buckling was developed at the side monocolumn region and then with increase of load the failure was extended to the connecting plates.
4. With further increase of loading, the steel tube in the side monocolumns was cracked. The failure happened in the concrete was only due to crushing.
5. In case of T shaped CFST columns connected with double vertical plates, the filing of concrete inside the plates helps to reduce the deformation of the steel plates significantly and also delay the local buckling.
6. When considering the load bearing capcity of those special shaped columns, T shaped CFST column connected with closed lacing bars shows a higher value apart from column with double vertical plates and lacing bars.

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