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Axial and Bending Performance of Spiral Stiffened Thin Walled CFDST Column

K.S. Siya[1], E. K. Amritha[2]
[1]P. G. Student, APJ Abdul Kalam Technological University, Department of Civil Engineering, Universal Engineering College, Irinjalakuda, Kerala, India.
[2] Associate Professor, Department of Civil Engineering, Universal Engineering College, Irinjalakuda, Kerala, India.

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Abstract: *CFDST columns are widely used in high rise buildings, bridges, transmission tower, etc. In this study the axial and bending performance of Concrete Filled Thin-Walled Double Skin Steel Tubular columns using ANSYS software are examined. It focuses on the effects of various factors on CFDST column, such as cross-section on spiral ribs and vertical ribs. The study introduces novel column configurations with spiral stiffeners, enhancing lateral strength and buckling efficiency. Analytical results demonstrate that spiral stiffeners outperform rectilinear tie reinforcement, improving concrete confinement. CFDST columns offer benefits like reduced steel consumption, less welding, and enhanced structural effectiveness. Additionally, internal hollows accommodate utilities like electrical cables, and the sandwiched concrete layers provide substantial fire resistance. The innovative design optimization method presented in this research promises to improve structural performance for infrastructure projects. The thin-walled CFDST columns show advantages in mechanical properties, weight reduction, and steel usage. This analysis reveals a 70% reduction in steel when replacing conventional CFDST columns with thin-walled versions.*

Key Word: *Concrete filled double skin steel tubes, Axial load, stiffened column, Ultimate deflection.*

I.INTRODUCTION

Composite columns are made of a variety of materials, each with a special set of properties, to maximize weight, rigidity, and load-bearing capability. Concrete-filled steel tube (CFST) columns are a common type among them. Because CFST columns offer improved structural performance and efficiency over standard steel or reinforced concrete components, they are becoming more and more common in high-rise structures, long-span bridges, and electrical transmission towers. CFST columns do have certain restrictions, though. Due to the concrete core's minimal contribution to torsional and flexural load-bearing, the steel tube's rigidity permits it to withstand higher loads under uniaxial compression, increasing column weight and seismic loads. Concrete-filled double skin steel tubular (CFDST) columns have been created as a solution to these problems. Concrete fills the space between an inner and an outer column that make up CFDST columns. High-rise buildings, bridges, industrial structures, subterranean structures, and transmission towers are among the civil engineering projects that use CFDST columns. Utilities such as electricity cables and drainage pipes can be housed in the inner tube cavity, which will stably support the concrete fill until the final strength is achieved. Because thin-walled CFDSTs solve the problem of inefficient material usage in regular CFDSTs, they offer significant cost savings by lowering the required amount of steel and welding. Nevertheless, thin-walled steel tubes are more likely to experience localized buckling under stress, which can result in poor ductility or brittle failure. They also have inferior resistance to fire and corrosion. Thus, it is necessary to find solutions for local buckling, fire resistance, and corrosion resistance in thin-walled steel tubes. CFDST columns are utilized in transmission towers, industrial structures, underground structures, high-rise skyscrapers, and bridges in civil engineering. Stiffeners are frequently used by engineers to reduce local buckling in thin-walled CFDST columns and improve the stability of steel tubes. In addition to proposing other stiffener kinds, such as double stiffeners, diagonal stiffeners, and perforated steel plate reinforcement stiffeners, Wang Z. S. [10] investigated the effects of vertical bars on thin-walled square steel tube concrete. According to the study's findings, adding stiffening ribs to steel tubes increases their capacity for localized buckling resistance, bearing, and deformation. The behavior of thin-walled CFDST members and the effects of steel reduction have been the subject of numerous investigations. Ayough [1] concentrated on compression analysis, while Ekmekyapar [2] investigated the effect of inner steel tubes on compression behavior. Despite extensive research on CFDST columns, the axial performance of spiral-stiffened thin-walled double skin composite columns has not been thoroughly explored. Wang [10] investigated the axial compression properties and factors influencing spiral-ribbed thin-walled square CFDST composite parts, while Wang [9] focused on axial compressive behavior with stiffeners. This study aims to address this gap by examining the axial performance of spiral-stiffened thin-walled double skin composite columns and the impact of steel reduction on CFDST columns.

II.ANALYTICAL STUDY

2.1 Modelling

In this study, a thin-walled CFDST column with vertical and horizontal spiral stiffeners of 1000 mm in height and 340 mm in width is modeled. Table 3 lists the additional dimensions. An analysis was conducted on the structural behavior and performance of CFDST columns using ANSYS software. Boundary conditions were positioned at the top and bottom of the column, and the meshing was completed using a 50-mm mesh size. Solid 185 was the element type used for concrete; Solid 186 was used for steel; Beam 188 was used for vertical bars, horizontal bars, and spiral stiffeners; and the element shape used for meshing was a hexahedron. Axial compressive loading was used as the loading method. The column is bottom end fixed & top end free. Table 1 [10] shows the material properties assigned for concrete, and Table 2 [10] shows the material properties assigned for steel.

- Solid 185 – Concrete
- Solid 186 – Steel Tube
- Beam 188 – Spiral ribs, Vertical Bars & Horizontal Bars

Table 1. Mechanical properties of concrete.

Description	Values
Compressive Strength	24.2 MPa
Modulus of Elasticity	29.7 GPa

Table 2. Mechanical properties of steel

Description	Yield Strength (MPa)	Ultimate Strength (MPa)	Elastic Modulus (10^5 MPa)
Steel Tude	278.70	388.93	2.06
Spiral Rib	256.94	363.79	2.03
Steel Bar	462.95	625.30	1.96

Table 3. Dimensions of each specimen.

Description	Dimensions (mm)
Specimen height	1000
Specimen width	340
Steel tube width	220
Steel thickness	1
Spiral rib width	30
Spiral rib thickness	3
Diameter of steel bar	14

III.WEIGHT COMPARISON OF THIN WALLED CFDST COLUMN WITH STIFFENERS AND THIN WALLED CFDST COLUMN WITHOUT STIFFENERS

3.1 CFDST column without stiffeners

A typical CFDST column is made up of an exterior column, an inner column, and concrete in between. The column will have a hollow area in the middle. Here thin walled CFDST column with stiffeners and without stiffeners are compared to compare the weights and structural performance. The geometry and cross section of CFDST column without stiffeners are shown in Fig. 1 and Fig. 2 respectively. An axial compressive load was applied in order to analyze this column. Using ANSYS Workbench, six models of CFDST columns without stiffeners, with thicknesses of 1 mm, 2 mm, 3 mm, 4 mm, 5 mm, and 6 mm for both inner & outer columns are analyzed. The ultimate load (UL), ultimate deflection (UD), and weights obtained for each column are given in Table 4.

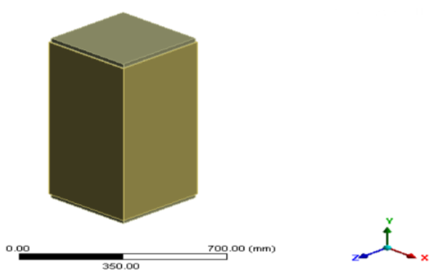

Fig. 1. Geometry of unstiffened CFDST.

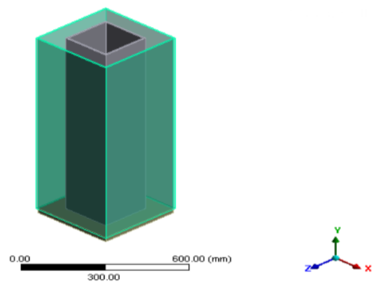

Fig. 2. Cross section of unstiffened CFDST.

3.2 CFDST column with stiffeners on both inner and outer columns

The structural performance of a CFDST column with 1 mm thickness, stiffened with vertical bars, spiral ribs, and horizontal bars on both its inner and outer walls was analyzed by applying an axial compressive load on ANSYS software. Fig. 3. depicts each component of the column independently, whereas Fig. 4. displays the column as a whole. The maximum load-bearing capacity, deflection, and total weight of the column were the main factors that were assessed. Using the load-deflection curve, these results were systematically compared with a CFDST column without stiffeners, as shown in Fig. 12. The maximum load (UD), deflection (UD), and weights obtained for each column are shown in Table 4. Fig. 5 depicts the hexahedron-shaped mesh with a dimension of 50 mm. Fig. 6 and Fig. 7 shows the column's support and loading conditions respectively. Here, spiral ribs of 3x30 mm dimension, along with vertical bars and horizontal bars measuring 14 mm in diameter. Refer to Fig. 3 for the arrangement of vertical bars, horizontal bars, and spiral stiffeners. These stiffeners are positioned on the internal side of the outer column and the external side of the inner column, where the concrete is placed.

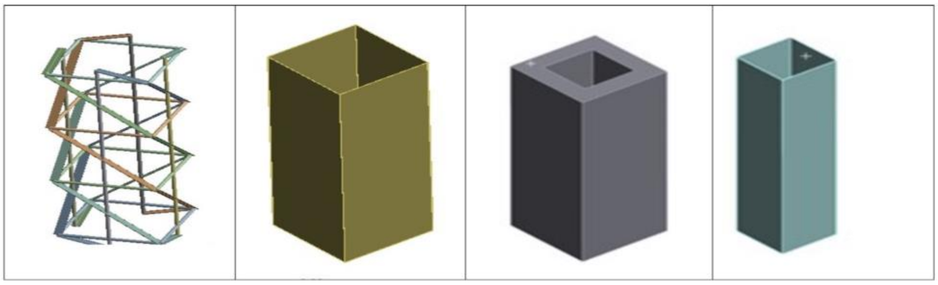

Fig. 3. Each component in CFDST stiffened column.

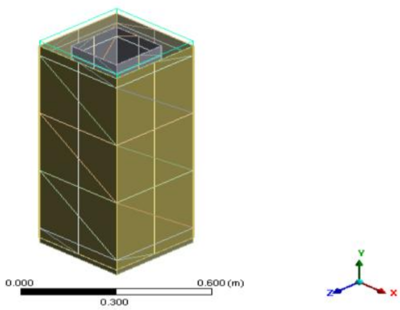

Fig. 4. Geometry of stiffened CFDST.

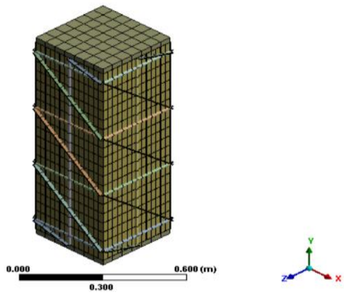

Fig. 5. Mesh diagram of CFDST.

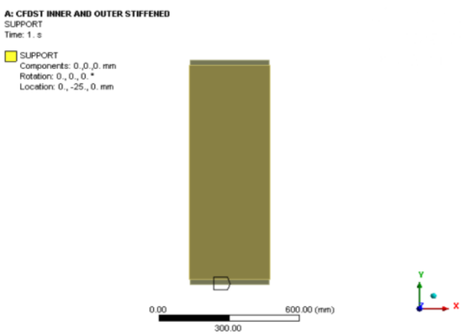

Fig. 6. Support of CFDST column.

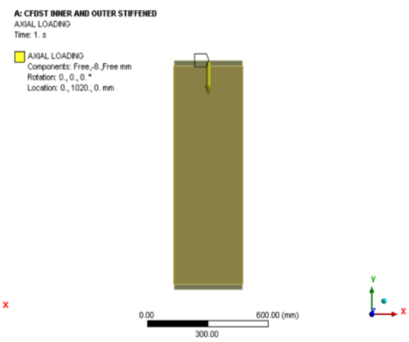

Fig. 7. Load of CFDST column.

3.3 Results and discussions

When the column is subjected to an axial load it receives a compressive stress along its length; if the load is greater than its capacity, this stress causes the column to deform. The CFDST column without stiffeners with 1mm, 2mm, 3mm, 4mm, 5mm, 6mm thicknesses and a CFDST column with inner and outer wall stiffened with vertical and horizontal bars od 14mm diameter and spiral ribs of 3X30 mm are analyzed and its ultimate load (UL), ultimate deflection (UD) and weights of each column are compared by using load deflection curve as shown in Fig. 12 and the data’s shown in Table 4. The ultimate load (UL) and ultimate deflection (UD) of each column is listed on Table 4. Fig. 8 and Fig. 9 shows the total deformation and plastic strain of CFDST column without stiffeners respectively and Fig. 10 and Fig. 11 shows the total deformation and plastic strain of CFDST column with stiffeners respectively.

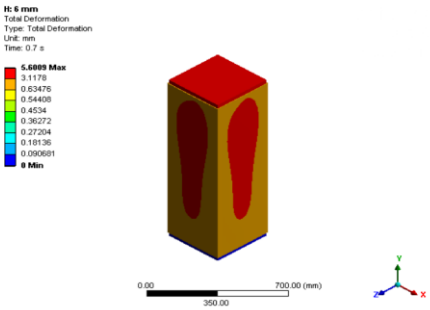

Fig. 8. Total deformation of Stiffened CFDST.

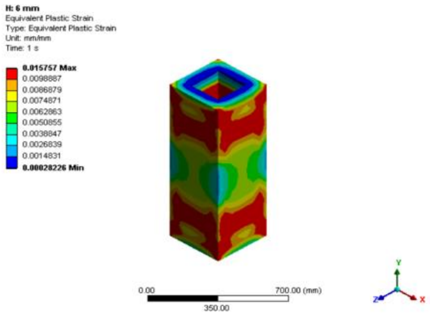

Fig. 9. Plastic strain of Stiffened CFDST.

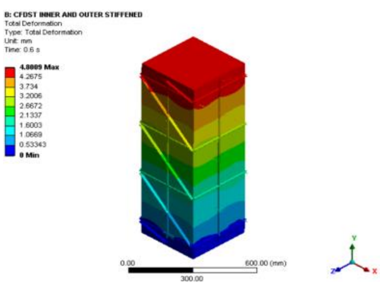

Fig. 10. Total deformation of unstiffened CFDST.

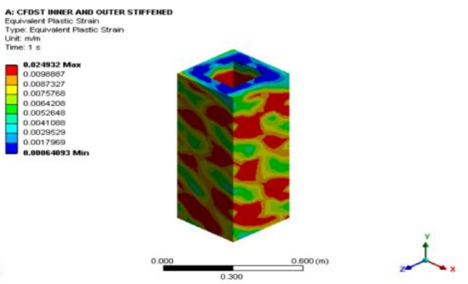

Fig. 11. Plastic strain of unstiffened CFDST.

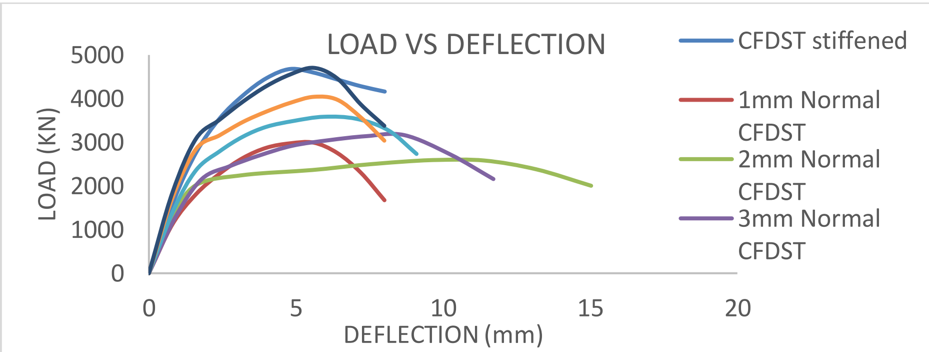

Fig. 12. Load Vs Deflection curve.

Table 4. Analysis of CFDST without stiffeners and CFDST with stiffeners.

Columns	UD (mm)	UL (kN)	Weight (kg)
1mm Normal	5.6001	2991.50	18.645
2mm Normal	9.8239	2595.10	37.29
3mm Normal	8.6776	3163.80	55.935
4mm Normal	5.958	3584.50	74.58
5mm Normal	5.6006	4041.20	93.225
6mm Normal	5.6009	4704.40	111.87
CFDST Stiffened	4.8009	4678.40	47.566

By comparing the ultimate loads (UL) of the CFDST column without stiffeners and the CFDST column with stiffeners from Table 4 and Fig. 12, it is very evident that the CFDST column without stiffeners with a 6 mm thicker inner and outer wall has a nearly equal ultimate load compared to the CFDST column with stiffeners of 1 mm thickness. Consequently, when comparing the weights of these columns, the CFDST column without stiffeners weighs 111.87 kg, whereas the CFDST column with stiffeners weighs 47.566 kg. Therefore, there is an approximate 70% reduction in steel weight and nearly equal load bearing capacity. So, a thin-walled CFDST column with stiffeners is an economic and high-performance column.

IV.ANALYSIS OF INNER TUBE (IT) STIFFENED CFDST COLUMN

Here, the CFDST column which is stiffened with spiral ribs, vertical bars and horizontal bars on the inner tube only. Various parametric studies have been conducted by altering the dimensions of spiral ribs and vertical bars. In these studies, the stiffeners are positioned on the outer side of the interior column. The parametric variations include square-shaped spiral stiffeners with dimensions of 3x30mm, 6x30mm, and 9x30mm, as well as circular-shaped spiral ribs with diameters of 10mm, 15mm, and 18mm. Additionally, another parametric study involves altering the dimensions of the vertical bars to diameters of 16mm, 18mm, and 20mm, without modifying the dimensions of any other members. The dimensions of the model are shown in Table 3.

4.1 Results and Discussions

The comparison of results from these parametric studies are shown in Table 5 and Fig. 15. These Parametric studies reveal that an Inner Tube stiffened CFDST column can attain an ultimate load (UL) comparable to that of a CFDST column stiffened on both inner tube and outer tube. Specifically, vertical bars with a diameter of 20mm by keeping spiral ribs 3X30mm significantly augment strength. Notably, this design achieves a substantial reduction in weight, making it a promising solution.

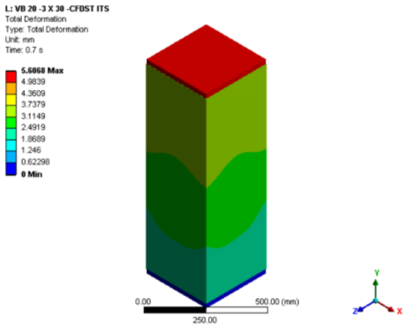

Fig. 13. Total deformation of IT stiffened CFDST.

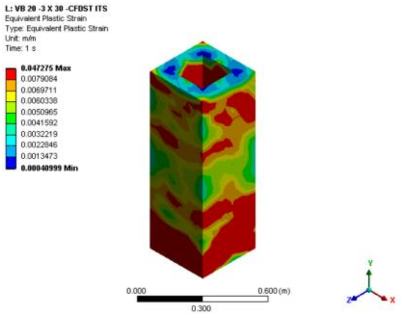

Fig. 14. Plastic strain of IT stiffened CFDST.

Table 5. Analysis of IT stiffened CFDST column.

Model	UD (mm)	UL (kN)	Weight (kg)
3X30 spiral	5.6007	3881.40	31.317
6X30 spiral	5.6008	4235.20	35.005
9X30 spiral	6.207	4336.50	38.693
10mm diameter spiral	6.2008	3979.80	30.847
15mm diameter spiral	5.6009	4119.40	34.871
18mm diameter spiral	5.6053	4434.90	39.249
16mm diameter vertical bar [VB]	5.601	4155.20	32.519
18mm diameter vertical bar [VB]	5.6029	4499.90	34.195
20mm diameter vertical bar [VB]	5.4046	4727.80	36.071

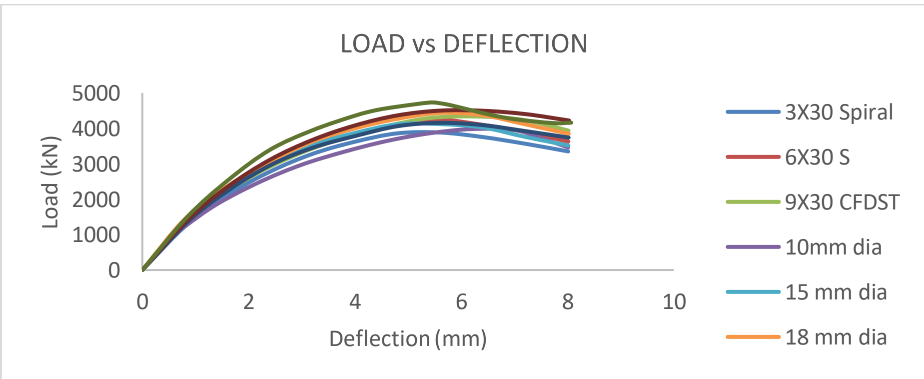

Fig. 15. Load Vs Deflection curve.

V.ANALYSIS OF OUTER TUBE (OT) STIFFENED CFDST COLUMN

The same parametric studies that are examined for CFDST columns stiffened on the inner tube are likewise examined for CFDST columns that are only stiffened on the outer tube to analyze the performance of the column while stiffened only on the outer tube. The dimensions of the column are shown in Table 3. The boundary conditions and meshing are the same as above. The column is analyzed under an axial compressive load.

5.1 Results and Discussions

Table 6. Analysis of OT stiffened CFDST column.

Model	UD (mm)	UL (kN)	Weight (kg)
3X30 Spiral	5.6002	3559.80	34.905
6X30 Spiral	5.6003	3688.10	39.751
9X30 Spiral	5.6003	3747.80	44.597
10mm diameter spiral	5.6002	3613.00	34.288
15mm diameter spiral	5.6002	3690.00	39.751
18mm diameter spiral	5.6003	3711.70	39.751
16mm diameter vertical bar [VB]	5.6002	3644.40	38.397
18mm diameter vertical bar [VB]	5.6003	3670.80	42.355
20mm diameter vertical bar [VB]	4.8003	3666.70	46.778

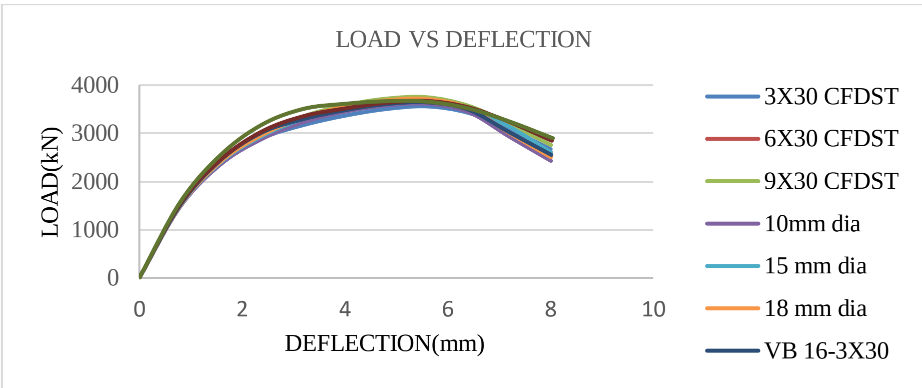

Fig. 16. Load Vs Deflection Curve.

VI.ANALYSIS OF BENDING PERFORMANCE OF THE COLUMN

After conducting studies on the inner tube stiffened CFDST column and the outer tube stiffened CFDST column, it is clear that the inner tube stiffened CFDST column with vertical bars of 20 mm diameter shows significant load-bearing capacity, as shown in Table 5 and Fig. 15. Hence, this model is taken for the analysis of bending performance of the column. Here we have done 25%, 50%, 75%, and 100% eccentricity.

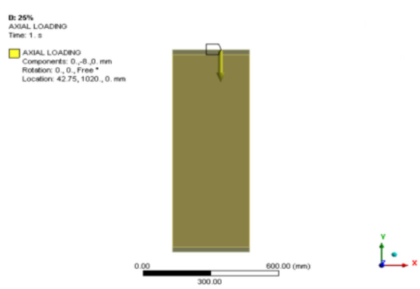

Fig. 17 Axial load on the column at 25%.

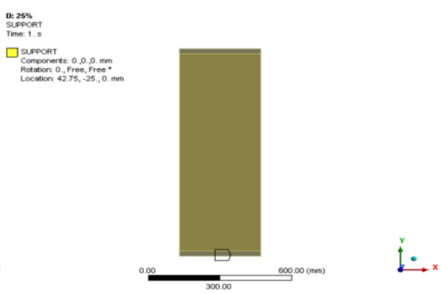

Fig. 18 Support on the column at 25 %.

6.1 Results and Discussions

Through eccentricity tests at various load and support placements away from the center of the column at 25%, 50%, 75%, and 100%, no sudden occurrences of bending are observed, even under extreme conditions. This highlights the robustness of the chosen design in mitigating bending stresses, particularly evident when subjected to a 25% eccentricity. This column stands out as a formidable solution for structural applications requiring superior performance and reliability.

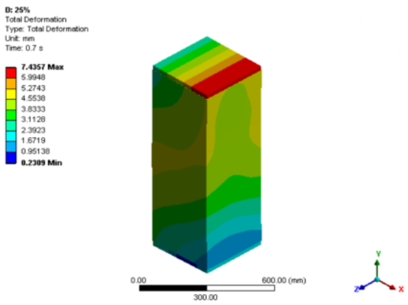

Fig. 19 Total deformation at 25%.

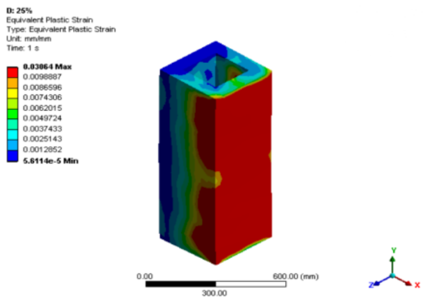

Fig. 20 Equivalent plastic strain at 25%.

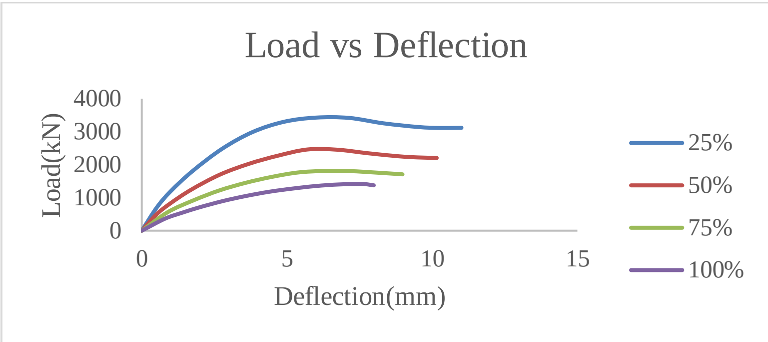

Fig. 21 Load Vs Deflection curve.

Table 7. Bending analysis of CFDST column with stiffeners on the inner tube.

Eccentricity	UD (mm)	UL (kN)
25% Eccentricity	6.0053	3429.50
50% Eccentricity	5.7108	2463.30
75% Eccentricity	6.2718	1810.90
100% Eccentricity	7.5883	1416.40

VII.CONCLUSIONS

This paper discusses the strength and behavior of thin-walled concrete-filled double-skin steel tubular (CFDST) columns under axial and eccentric loading. A number of CFDST specimens underwent testing, and parametric studies were conducted on vertical bars and spiral ribs by altering their cross-sections on both the inner and outer walls of the columns. Load vs. deflection curves were analyzed to assess the performance of the column. Subsequently, all models were compared, allowing for conclusions to be drawn within the study's scope. Comparing CFDST columns without stiffeners and CFDST columns with inner and outer wall stiffeners reveals significant results. Despite the column without stiffeners with 6 mm thickness, weighing 111.87 kg, and bearing an ultimate load of 4704.40 kN, the thin-walled stiffened CFDST column, weighing only 47.566 kg, achieves a comparable ultimate load of 4678.40 kN. This suggests a remarkable 70% reduction in steel usage while maintaining similar load-bearing capacity, which means thin walled CFDST stiffened column with 1 mm thickness can bear almost same load bearing capacity when compared to CFDST column without stiffeners with 6 mm thickness. Various parametric studies were conducted on thin-walled CFDST columns with only inner wall is stiffened, focusing on spiral ribs and vertical bars. Optimal configurations, such as using 20mm-diameter vertical bars alongside 3x30mm spiral ribs, significantly enhance strength while comparing with spiral ribs and vertical bars of other cross section as mentioned in Table 5, which achieves an ultimate load of 4727.80 kN and a weight of 36.071 kg. Similar studies on columns with only outer wall stiffened with same parametric studies on spiral ribs and vertical bars were also undertaken. From this analysis, it is clear that the thin-walled inner-wall stiffened CFDST column shows considerable strength and a significant weight reduction compared to other models which is, CFDST column with both inner and outer wall stiffened and CFDST column with only outer wall stiffened. This is because in short columns, the middle portion of the column takes most of the loads under compression, so strengthening the inner column, which is the middle portion, is the better option to increase the strength of the CFDST column. It can also reduce the amount of welding because only the inner wall has to be stiffened. The IT-stitched CFDST column, featuring vertical bars of 20 mm diameter and spiral ribs of 3 x 30 mm, demonstrates remarkable resilience against bending, so this model is also subjected to eccentric loading to analyze the bending performance. Through eccentricity tests at various load placements away from the center line of the column (25%, 50%, 75%, and 100%), no sudden occurrences of bending are observed, even under extreme conditions. This highlights the robustness of the chosen design in mitigating bending stresses, particularly evident when subjected to a 25% eccentricity. This column stands out as a formidable solution for structural applications requiring superior performance and reliability.

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