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PARAMETRIC ANALYSIS OF ECC AND UHPC FILLED DOUBLE STEEL TUBULAR COMPOSITE COLUMNS USING ANSYS

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Abstract

The study on the Parametric Analysis of Engineered Cementitious Composite (**ECC**) and Ultra-High-Performance Concrete (**UHPC**) Filled Double Steel Tubular Composite Columns explores the structural performance of these advanced composite columns under axial compression and varying parametric conditions. Double steel tubular composite columns, widely used in high-rise and heavy-load structures, exhibit superior strength and durability when filled with ECC and UHPC due to their high ductility, impact resistance, and crack control properties. This research employs finite element modelling to analyse the effects of key parameters such as steel tube thickness, steel tube diameter, slenderness ratio, and material properties on load-bearing capacity, deformation behaviour, and energy absorption.

Additionally, the study incorporates stiffeners—vertical, circular, and diagonal—within the composite columns to enhance strength, prevent local buckling, and improve load-carrying efficiency. Stiffeners contribute to increased stability, reduced deformation, and efficient load transfer, reinforcing the structural integrity of the columns. A detailed failure mechanism analysis is conducted to assess the impact of these reinforcements under varying conditions. The research findings provide valuable insights into optimizing design parameters for improved structural resilience, weight efficiency, and service life, offering engineers data-driven guidelines for safer and more efficient high-rise buildings and large-scale infrastructure projects.

***Key Words*: ECC, UHPC, Double Steel Tubular Composite Columns, Axial Compression, Finite Element Modelling, Stiffeners, Load-Bearing Capacity, Deformation, Local Buckling, Structural Integrity.**

1. INTRODUCTION

The parametric analysis of Engineered Cementitious Composites (**ECC**) and Ultra-High-Performance Concrete (**UHPC**) filled double steel tubular composite columns is a crucial research area in structural engineering. These columns, consisting of inner and outer steel tubes filled with ECC between the steel tubes and UHPC in the core, offer superior load-bearing capacity, ductility, and durability, making them ideal for high-rise buildings, bridges, and heavy-load structures. The unique material combination of **ECC** and **UHPC** enhances the column's overall performance by providing high compressive strength, crack resistance, and energy absorption.

In this study, stiffeners are introduced to further improve structural stability. These stiffeners are incorporated within the double steel tubular columns to prevent local buckling, enhance load transfer, and optimize overall strength. The research involves a detailed parametric analysis using finite element modelling, investigating variables such as steel tube thickness, steel tube diameter, slenderness ratio, stiffener configurations, and material properties to optimize the structural behaviour under axial and eccentric loading conditions.

1.1 Engineered Cementitious Composite (ECC)

Engineered Cementitious Composite (**ECC**), often referred to as "bendable concrete," is a fibre-reinforced cementitious material known for its high ductility, crack control, and energy absorption properties. Unlike conventional concrete, which is brittle and prone to cracking, ECC forms multiple micro-cracks under stress, allowing it to maintain structural integrity even in extreme conditions.

ECC is composed of cement, sand, water, chemical additives and microfibres that improve its tensile properties. These microfibres help bridge cracks and distribute stress efficiently, making ECC ideal for earthquake resistant structures, bridge decks, pavements, and high-durability infrastructure. The material's superior flexibility and long-term durability reduce maintenance costs and enhance sustainability in modern construction.

1.2 Ultra-High-Performance Concrete (UHPC)

Ultra-High-Performance Concrete (UHPC) is an advanced form of concrete that provides exceptional mechanical strength and durability, significantly surpassing conventional concrete. With compressive strength exceeding 120 MPa, UHPC is widely used in critical infrastructure projects such as bridges, high-rise buildings, and military structures.

UHPC consists of fine aggregates, high-quality cement, silica fume, superplasticizers, and steel fibres, which create a dense microstructure resistant to abrasion, chemical attacks, and freeze-thaw cycles. The inclusion of steel fibres enhances tensile strength and toughness, preventing brittle failure under high-stress conditions.

Additionally, UHPC exhibits self-healing properties, where micro-cracks seal over time, further extending the material's service life. Despite challenges such as high initial cost and complex mix design, ongoing research is making UHPC a more accessible and efficient solution for long-lasting and sustainable construction.

1.3 Mild Steel (FE250)

Mild steel (FE250) is widely used in structural applications due to its balanced strength, ductility, and cost-effectiveness. Classified under IS 2062 standards, FE250 has a minimum yield strength of 250 MPa, making it suitable for medium-load structures such as beams, columns, and frames in buildings and bridges.

Its low carbon content enhances weldability, formability, and ductility, allowing for easy fabrication and stress absorption without fracturing. Although it does not provide the high tensile strength of alloyed steels, FE250 compensates with affordability and versatility. It is also corrosion-resistant when treated or coated, expanding its usability in various environmental conditions.

1.4 Stiffeners in Double Steel Tubular Composite Columns

To enhance the structural integrity of double steel tubular composite columns, stiffeners are incorporated in different configurations. These stiffeners help in preventing local buckling, improving stress distribution, and increasing overall load-bearing capacity. The following types of stiffeners are introduced in this study:

1.4.1 Vertical Stiffeners

- Placed along the height of the column.
- Provide additional axial strength and reduce deformation.
- Enhance buckling resistance under axial and lateral loads.

1.4.2 Circular Stiffeners

- Positioned at regular intervals inside the column.
- Improve confinement effect by distributing loads more evenly.
- Increase local stability and prevent distortion of the inner and outer steel tubes.

1.4.3 Diagonal Stiffeners

- Placed at an angle between the inner and outer tubes.
- Enhance shear resistance and energy absorption.
- Improve load transfer efficiency, especially in seismic conditions.

By integrating these stiffeners with ECC and UHPC, the columns achieve higher strength, stability, and resilience, making them more efficient for modern structural applications.

2. SCOPE AND OBJECTIVE OF THE STUDY

This study focuses on the **parametric analysis** of **ECC and UHPC-filled double steel tubular (EUFDST) composite columns** under axial compression using finite element modelling in ANSYS. It examines the **influence of key design parameters, including steel tube thickness, steel tube diameter, slenderness ratio, and stiffener configurations (vertical, circular, and diagonal)** on the structural performance of EUFDST columns. The research aims to optimize these parameters for improved **load-bearing capacity, deformation behaviour, and energy absorption, making the findings applicable to high-rise buildings, bridges, and heavy-load infrastructure**.

- To conduct a parametric analysis of ECC and UHPC-filled double steel tubular composite columns under axial loading.
- To evaluate the effect of key dimensional parameters on the structural performance of the columns, including:
  - L/D ratio and its impact on buckling behaviour.
  - Steel tube diameter and its influence on load-bearing capacity.
  - Steel tube thickness and its role in confinement efficiency and ductility.

- To analyse the contribution of different stiffener configurations in enhancing column strength and stability, specifically:
  - **Vertical stiffeners** for controlling local buckling.
  - **Circular stiffeners** for improving confinement and load distribution.
  - **Diagonal stiffeners** for increasing shear resistance and overall structural integrity.
- To compare the ultimate load-carrying capacity and deflection of composite columns with different material infill (**ECC** and **UHPC**) and stiffener arrangements.
- To optimize the design of double steel tubular composite columns by identifying the most effective combination of material properties, dimensional parameters, and stiffener configurations for improved structural performance.

3. MODELING AND ANALYSIS

The Finite Element Method (FEM) is a numerical analysis technique used to approximate engineering solutions by dividing structures into smaller finite elements, assembled at nodes. It employs shape functions to approximate displacement, strain, and stress, while the virtual displacement principle is used to derive equilibrium equations.

ANSYS 2024 R2 Workbench is utilized for nonlinear static analysis to evaluate the structural performance of EUFDST composite columns. Advanced features like sub-modelling, random vibration, and design optimization enhance accuracy in simulations.

The study involves 25 models, including 13 with stiffeners (vertical, circular, and diagonal), analysed under axial compression and eccentric loading conditions. Key output parameters include load capacity, deflection, stress distribution, and failure modes, which help assess the structural performance of the composite columns.

For finite element modelling, SOLID65 is used for concrete, simulating cracking and crushing effects, while SOLID186, a higher-order 3D element, ensures precise stress calculations. CONTA174 and TARGE170 handle contact interactions between structural components.

Material modelling in Finite Element Analysis (FEA) includes nonlinear material models for concrete and steel. The concrete model incorporates cracking, crushing, and plasticity, whereas the steel model considers yielding, strain hardening, and ductility to ensure realistic structural behaviour.

This FEM-based study provides insights into the structural behaviour, load resistance, and failure mechanisms of **EUFDST** composite columns. The inclusion of stiffeners further enhances stability and strength, contributing to optimized structural design and performance prediction.

Table -1: Parametric Data

Models	Outer tube Dia	Thickness	Inner tube Dia	Thickness	Slenderness ratio	Height	Loading	
	mm	mm	mm	mm	λ	mm	0% (Axial)	100% (Eccentricity)
M3-1	219.1	4.8	168.3	4.5	3	657.3	0	109.55
M3-2	219.1	4.8	60.3	2.9	3	657.3	0	109.55
M6-1	219.1	4.8	168.3	4.5	6	1314.6	0	109.55
M6-2	219.1	4.8	60.3	2.9	6	1314.6	0	109.55
M9-1	219.1	4.8	168.3	4.5	9	1971.9	0	109.55
M9-2	219.1	4.8	60.3	2.9	9	1971.9	0	109.55

Table -2: Parameters of Reference Model

Model	Outer tube Dia	Thickness	Inner tube Dia	Thickness	Slenderness ratio	Height	Loading
	mm	mm	mm	mm	λ	mm	0% (Axial)
M3-2	219.1	4.8	60.3	2.9	3	657.3	0

Table -3: Parameters of Vertical Stiffeners

Width(mm)	Thickness(mm)	Area(mm^2)	Number	Total steel area(mm^2)
25	2.5	62.5	16	1000
25	5	125	8	1000
25	10	250	4	1000

Table -4: Parameters of Circular Stiffeners

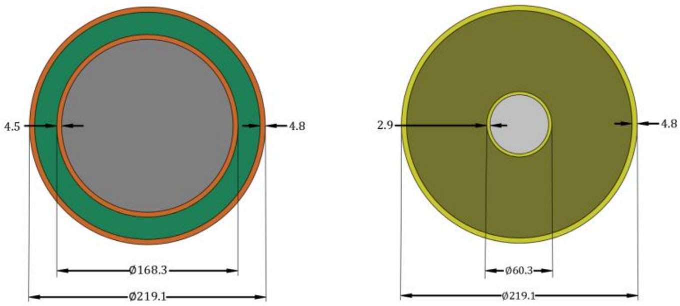
Width(mm)	Thickness(mm)	Number	Total steel area(mm^2)
30	2.5	16	1200
30	5	8	1200
30	10	4	1200

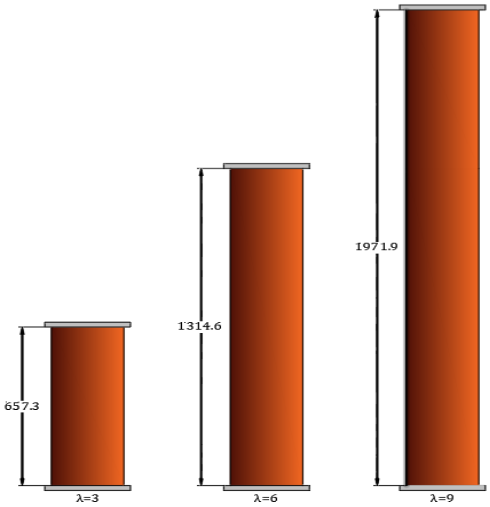
Table -5: Parameters of Diagonal Stiffeners

Diameter(mm)	Area(mm^2)	Number	Total steel area(mm^2)
10	78.5	16	1256
14.14	157	8	1256
20	314	4	1256

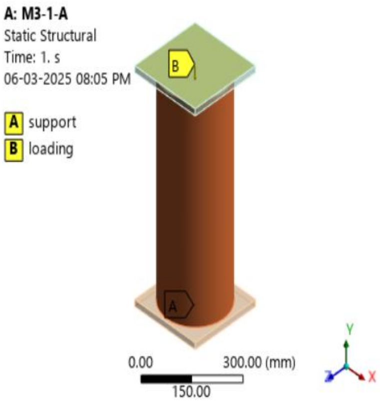
4. GEOMETRY OF COLUMNS

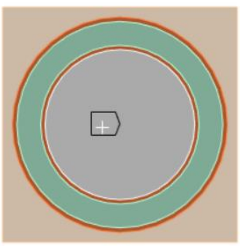
4.1 EUFDST Composite Column parameters

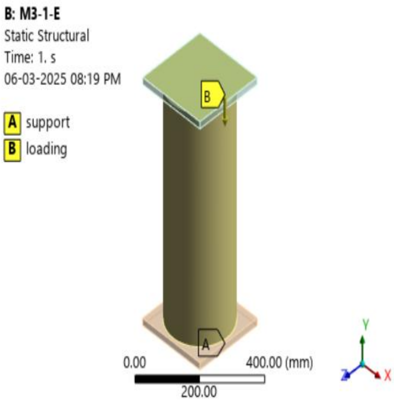


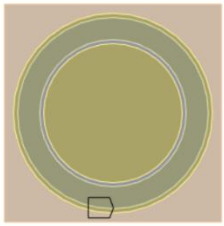


4.2 Axial and Eccentric loading boundary conditions



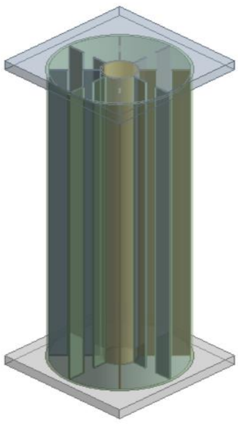


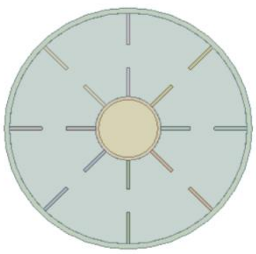




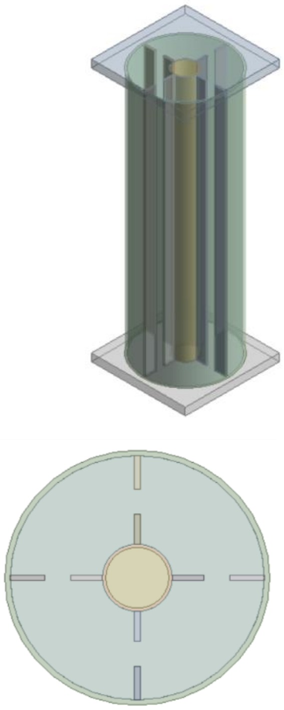
4.3 Arrangements of different types of Stiffeners

4.3.1 Vertical stiffeners

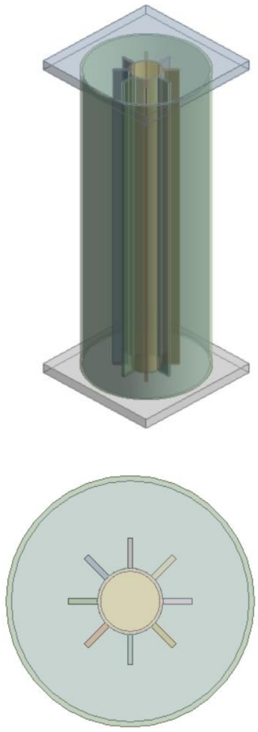




M3-2-A IO-16S



M3-2-A IO-8S



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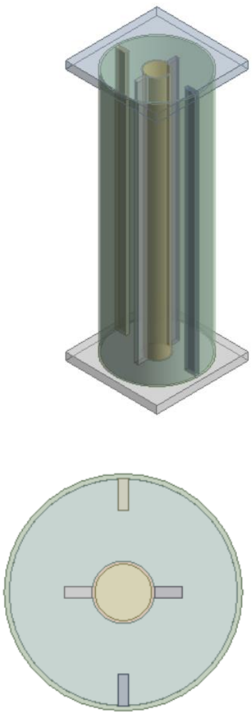
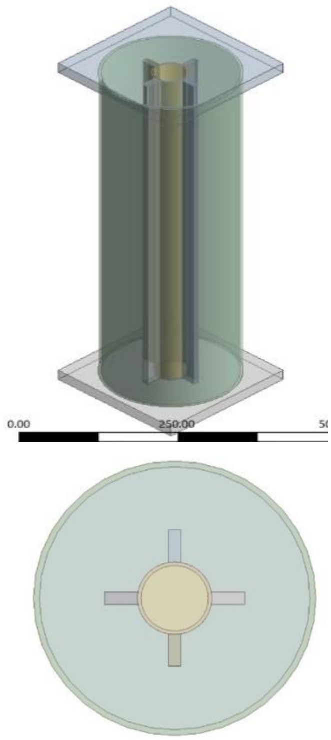
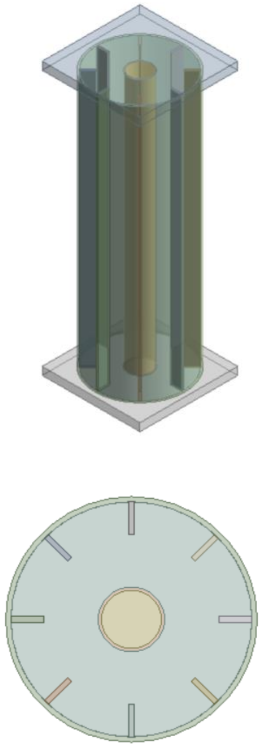


M3-2-A IO-4S



M3-2-A I-4S



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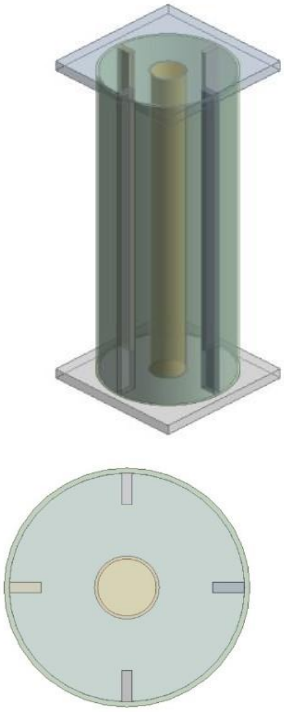
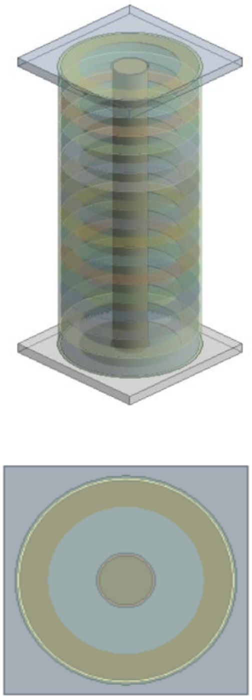
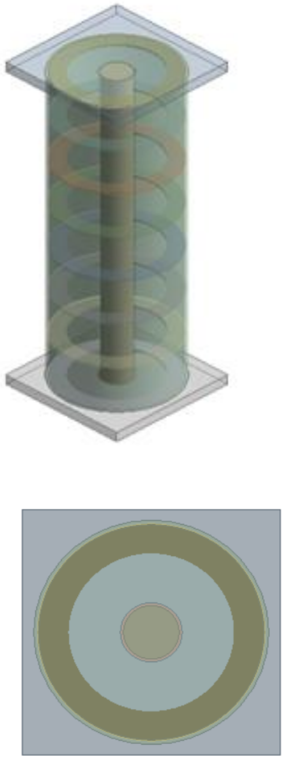


M3-2-A O-4S

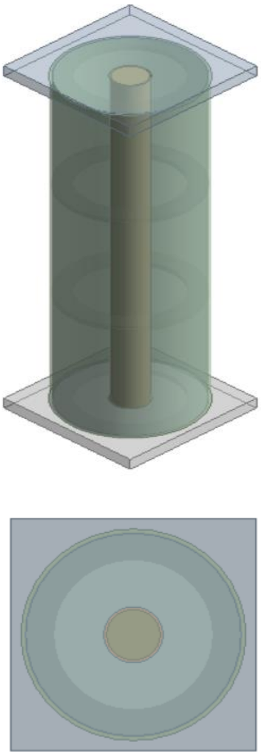
4.3.2 Circular stiffeners



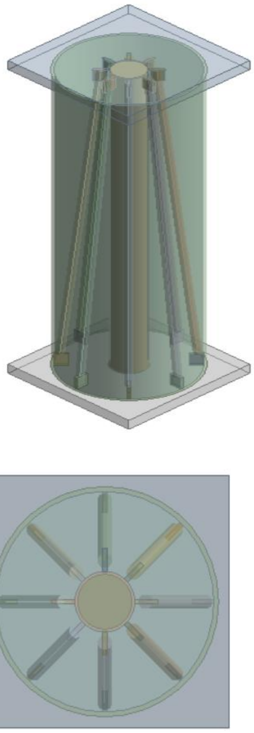
CIRCULAR-16S



CIRCULAR-8S

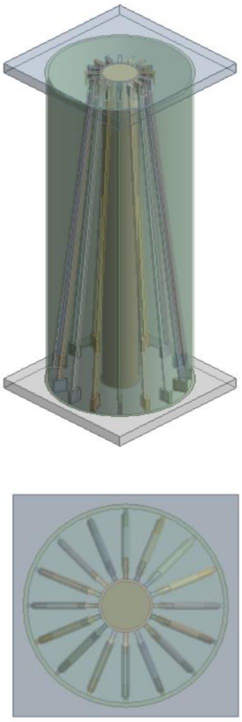


CIRCULAR-4S



DIAGONAL-8S

4.3.3 Diagonal stiffeners



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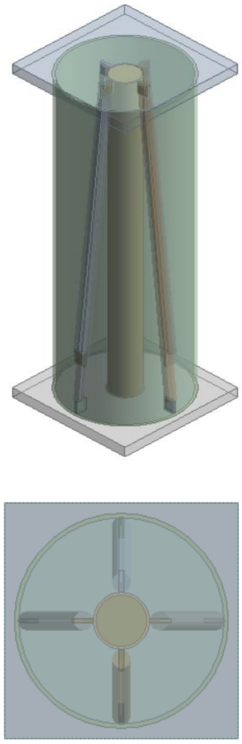

DIAGONAL-4S

5. RESULTS AND DISCUSSIONS

5.1 Results and Discussions of EUFDST Composite Columns

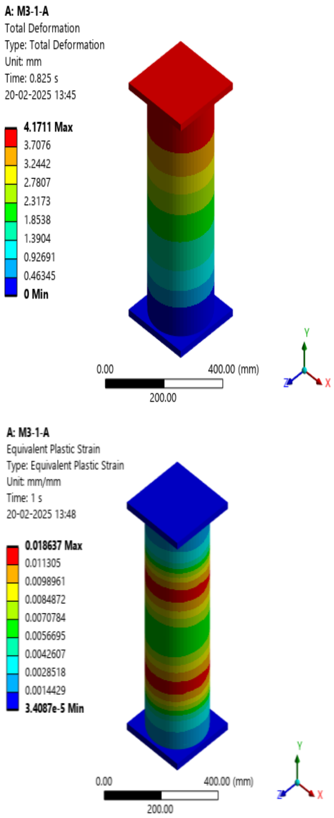

Fig-1: M3-1- Axial (Inner tube Dia=168.3 mm)

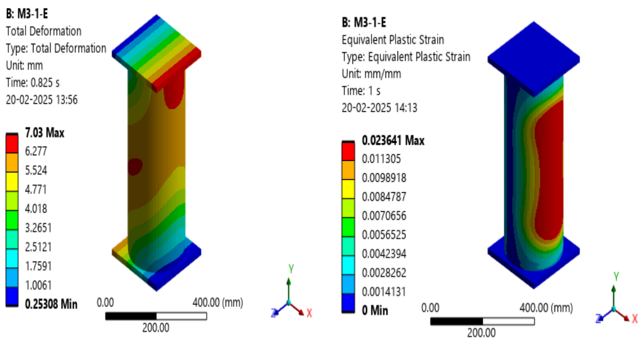

Fig-2: M3-1- Eccentric (Inner tube Dia=168.3 mm)

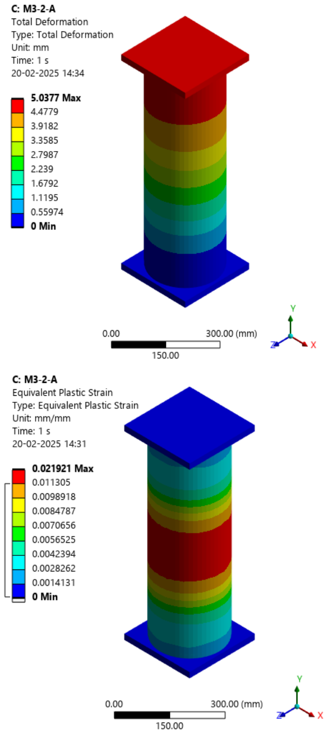

Fig-3: M3-2- Axial (Inner tube Dia =60.3 mm)

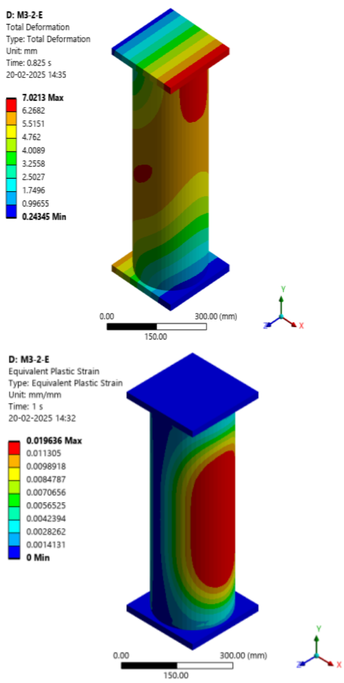

Fig-4: M3-2- Eccentric (Inner tube Dia =60.3 mm)

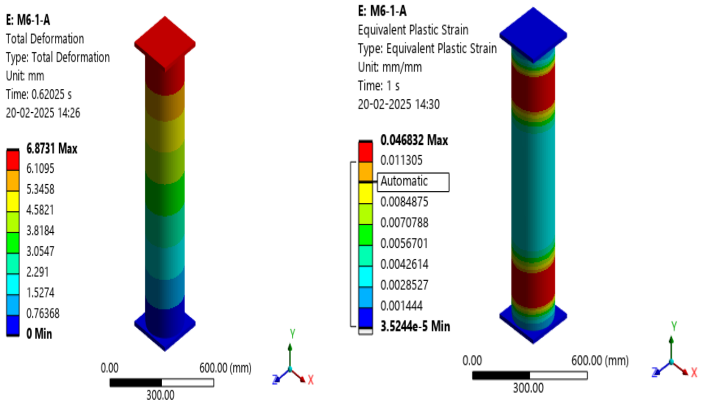

Fig-5: M6-1- Axial (Inner tube Dia=168.3 mm)

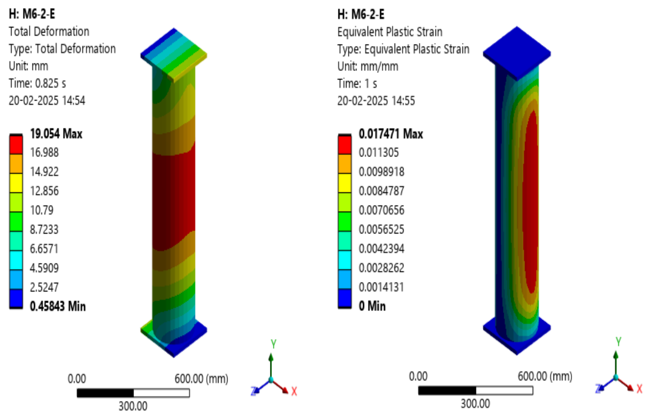

Fig-8: M6-2-Eccentric (Inner tube Dia =60.3 mm)

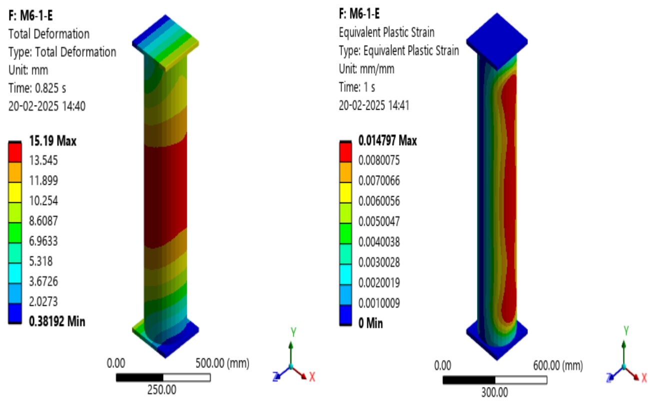

Fig-6: M6-1- Eccentric (Inner tube Dia=168.3 mm)

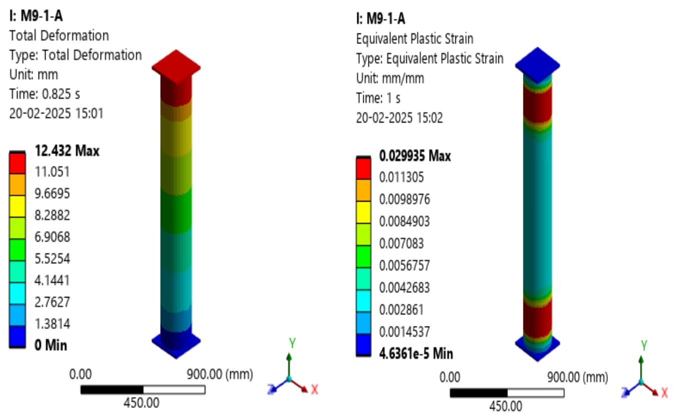

Fig-9: M9-1- Axial (Inner tube Dia=168.3 mm)

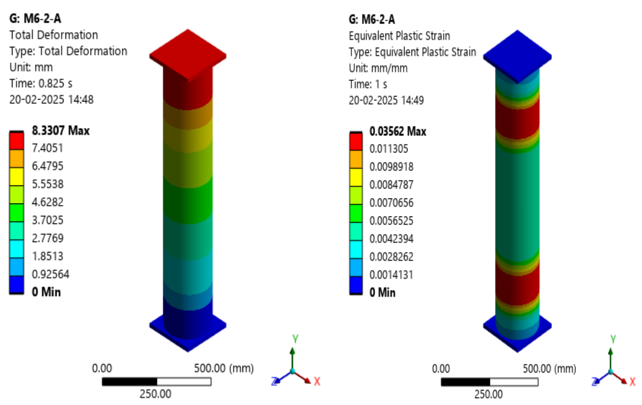

Fig-7: M6-2- Axial (Inner tube Dia =60.3 mm)

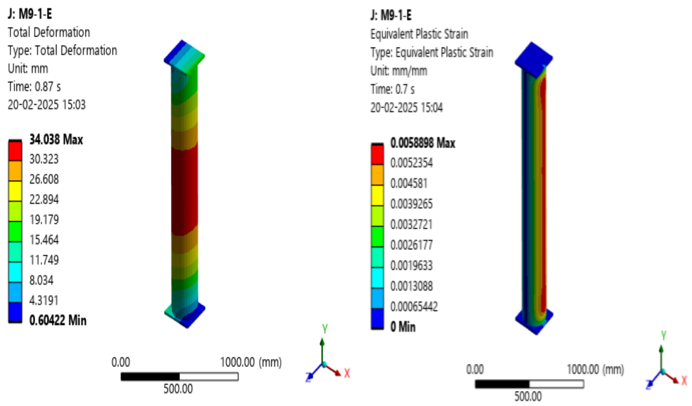

Fig-10: M9-1- Eccentric (Inner tube Dia=168.3 mm)

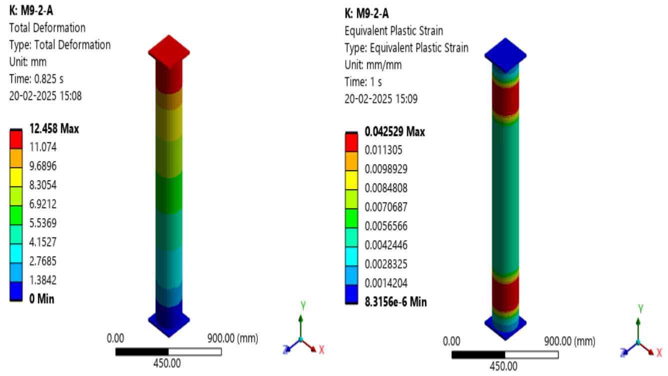

Fig-11: M9-2- Axial (Inner tube Dia =60.3 mm)

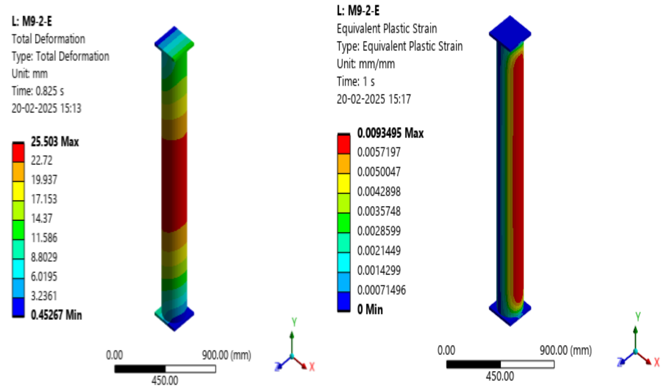

Fig-12: M9-2- Eccentric (Inner tube Dia =60.3 mm)

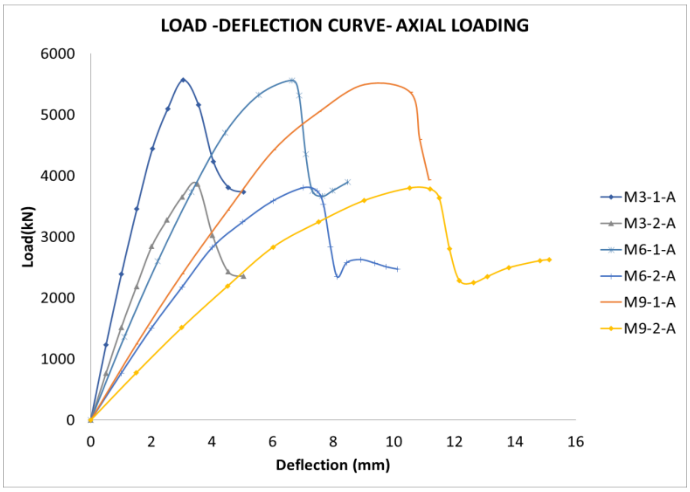

Fig-13: Load-Deflection curve under Axial Loading

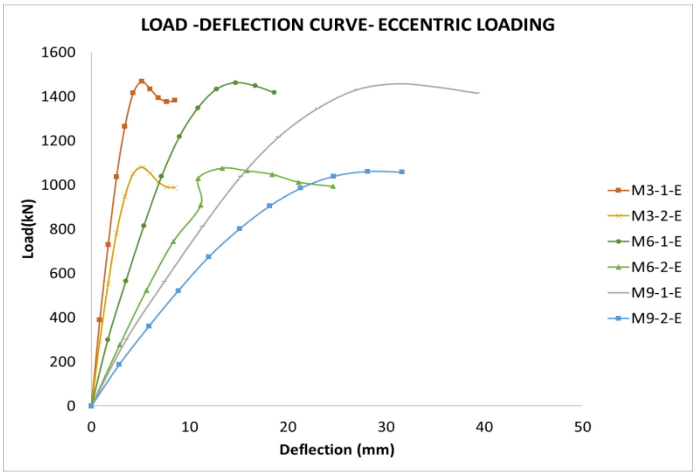

Fig-14: Load-Deflection curve under Eccentric Loading

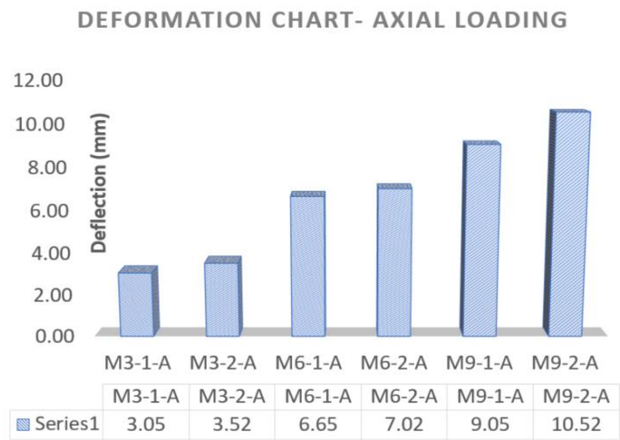

Fig-15: Deformation Comparison chart under Axial Loading

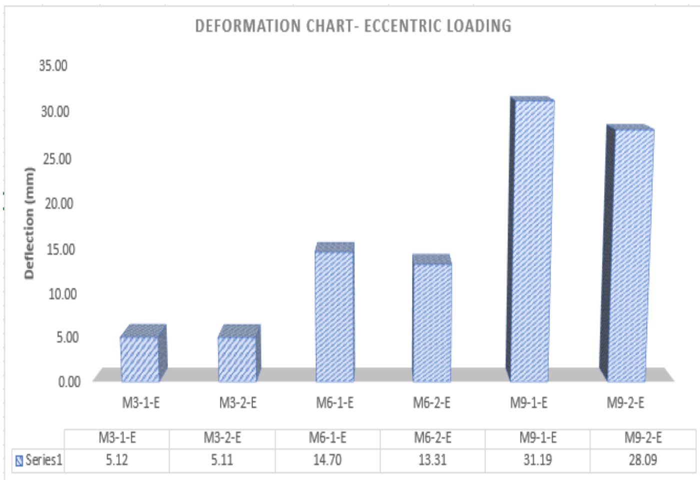

Fig-16: Deformation Comparison chart under Eccentric Loading

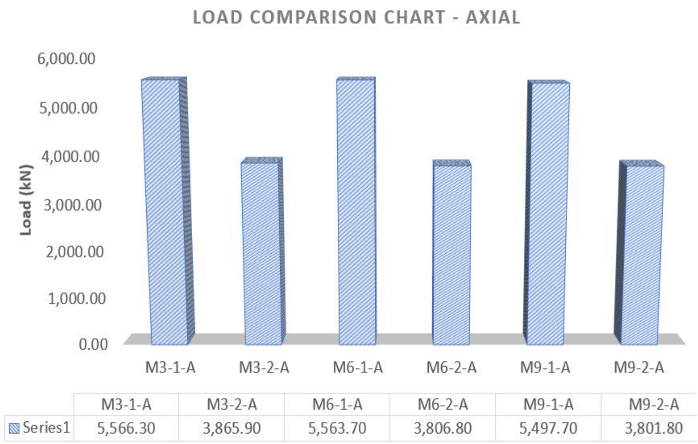

Fig-17: Load Comparison chart under Axial Loading

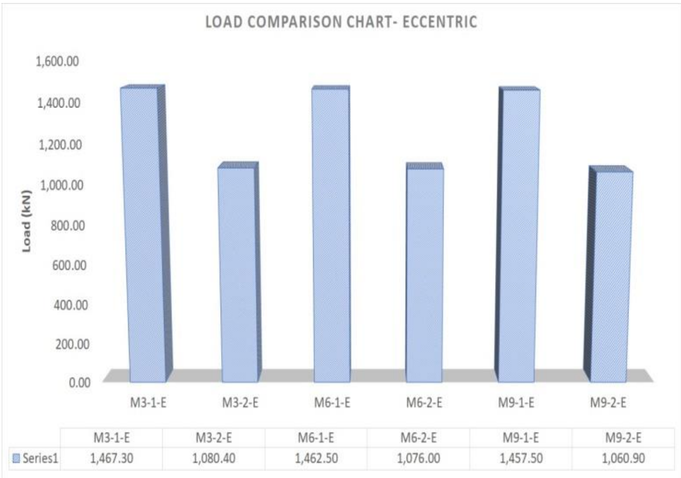

Fig-18: Load Comparison chart under Eccentric Loading

5.2 Results and Discussions of EUFDST Composite Columns with Stiffeners

5.2.1 Vertical Stiffeners

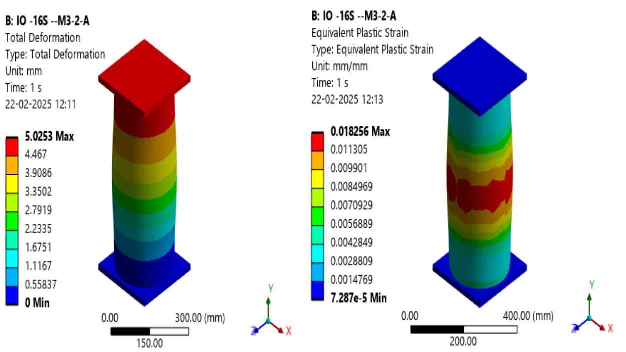

Fig-19: M3-2A EUFDSTCC with 16 Inner and Outer Vertical Stiffeners

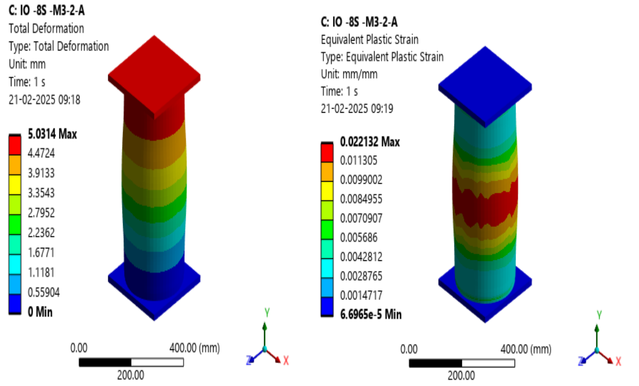

Fig-20: M3-2A EUFDSTCC with 8 Inner and Outer Vertical Stiffener

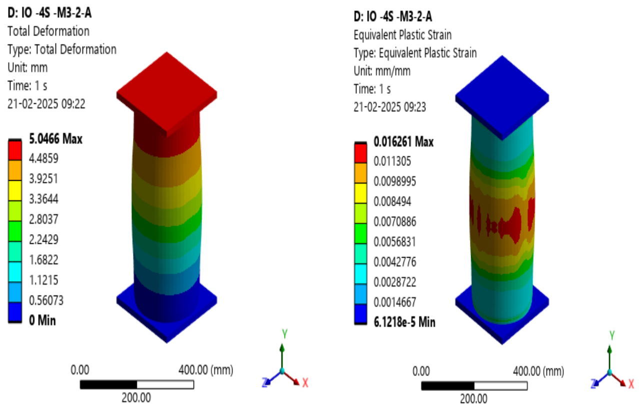

Fig-21: M3-2A EUFDSTCC with 4 Inner and Outer Vertical Stiffeners

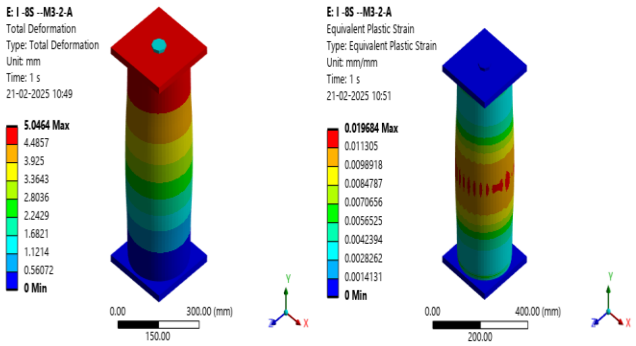

Fig-22: M3-2A EUFDSTCC with 8 Inner Vertical Stiffeners

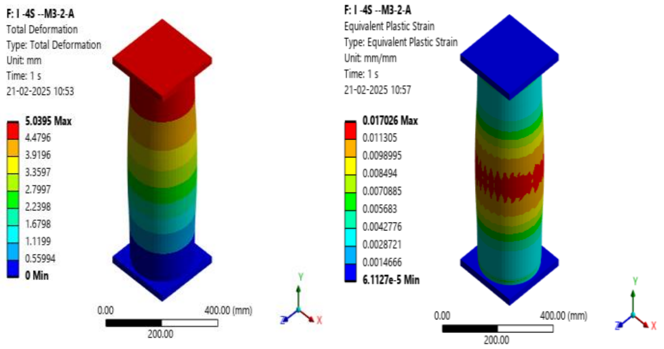

Fig-23: M3-2A EUFDSTCC with 4 Inner Vertical Stiffeners

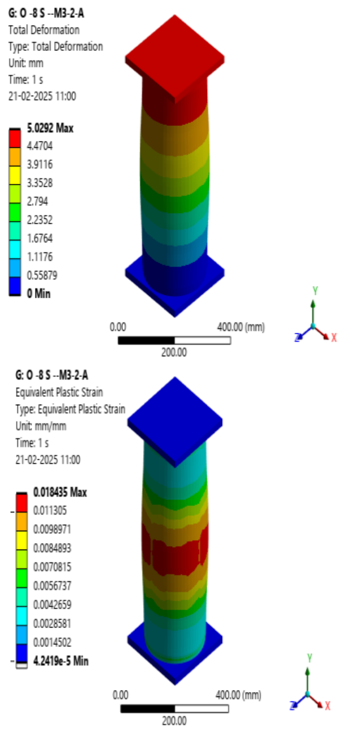

Fig-24: M3-2A EUFDSTCC with 8 Outer Vertical Stiffeners

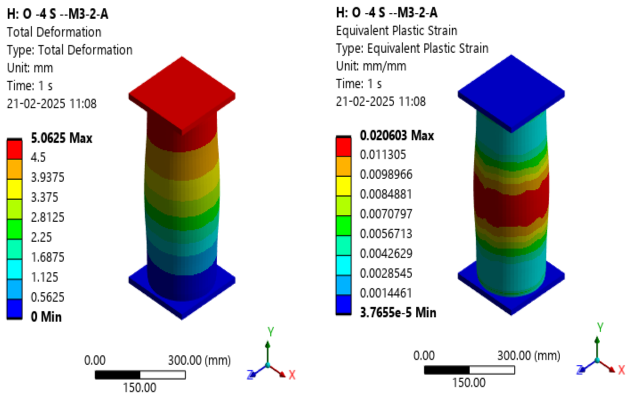

Fig-25: M3-2A EUFDSTCC with 4 Outer Vertical Stiffeners

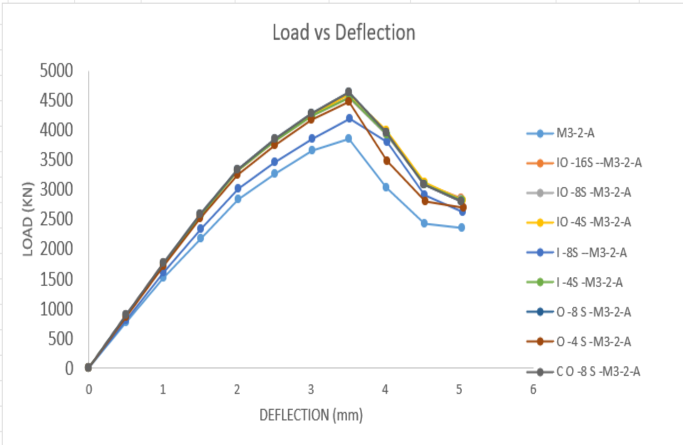

Fig-26: Load vs Deflection curve

Fig-27: Deformation comparison chart

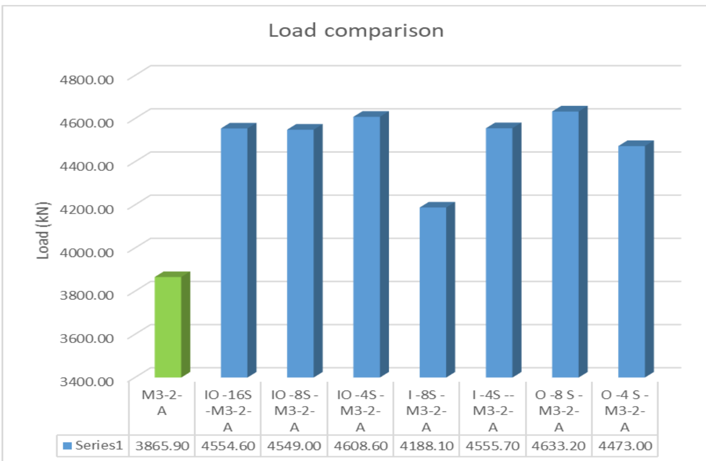

Fig-28: Load comparison chart

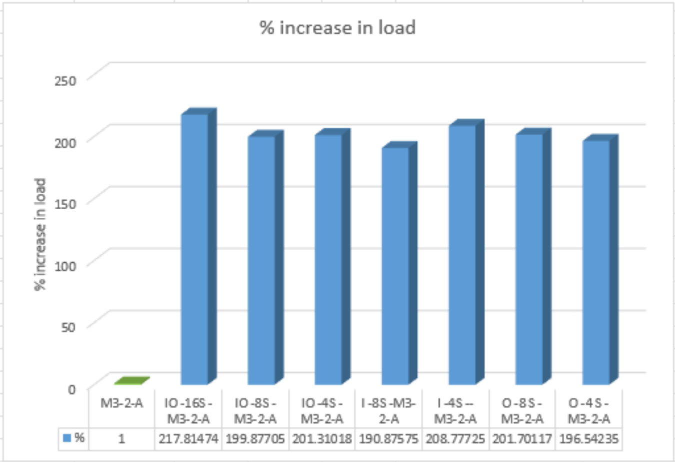

Fig-29: % Increase in Load chart

5.2.2 Circular Stiffeners

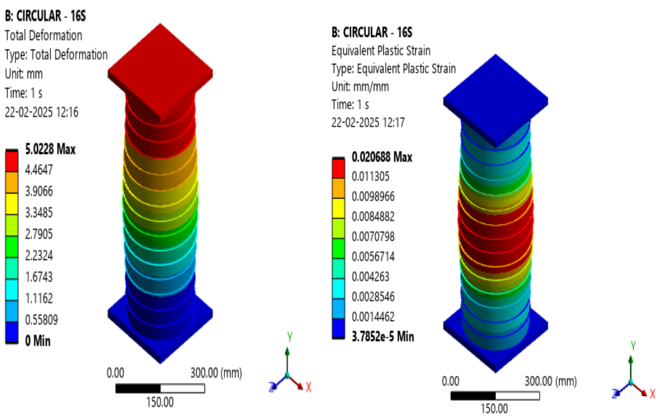

Fig-30: M3-2A EUFDSTCC with 16 Circular Stiffeners

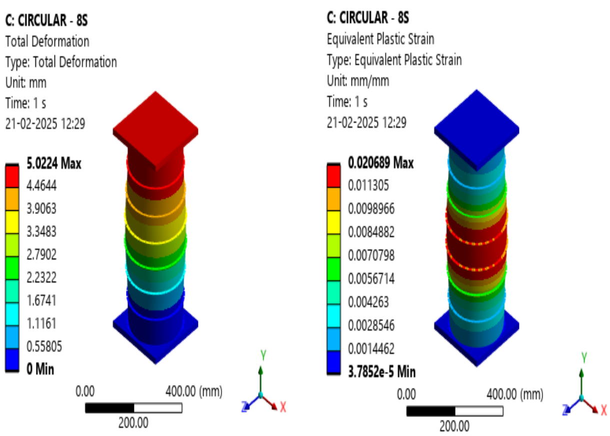

Fig-31: M3-2A EUFDSTCC with 8 Circular Stiffeners

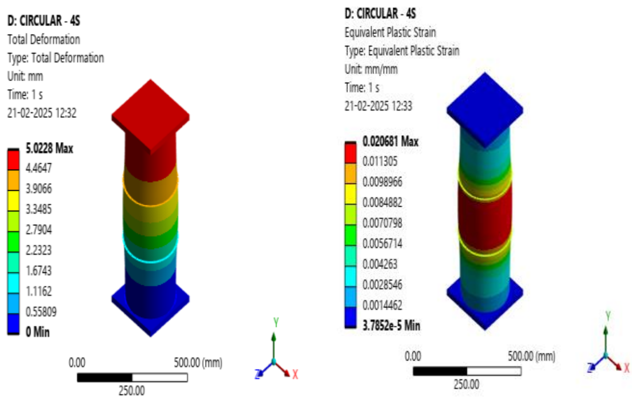

Fig-32: M3-2A EUFDSTCC with 4 Circular Stiffeners

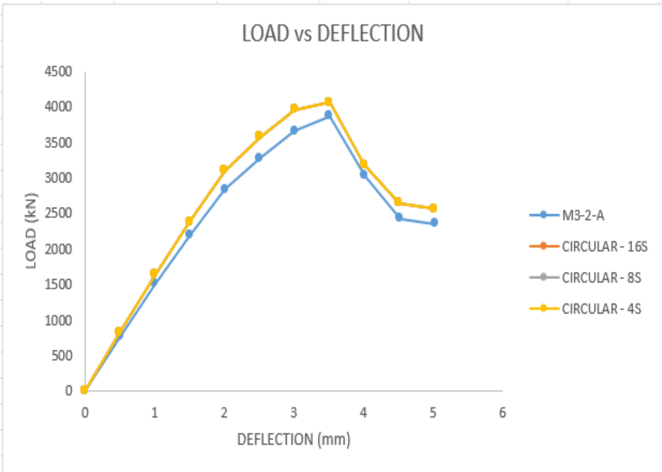

Fig-33: Load vs Deflection curve

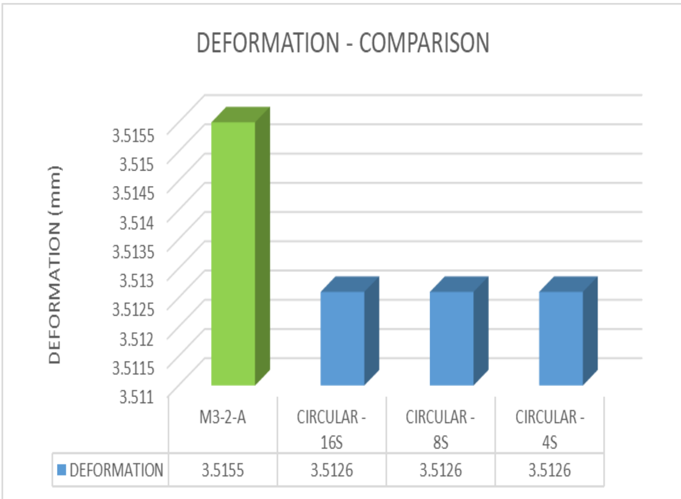

Fig-34: Deformation comparison chart

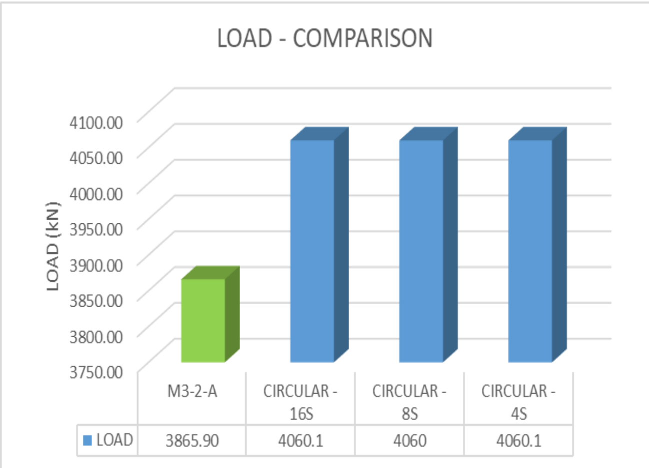

Fig-35: Load comparison chart

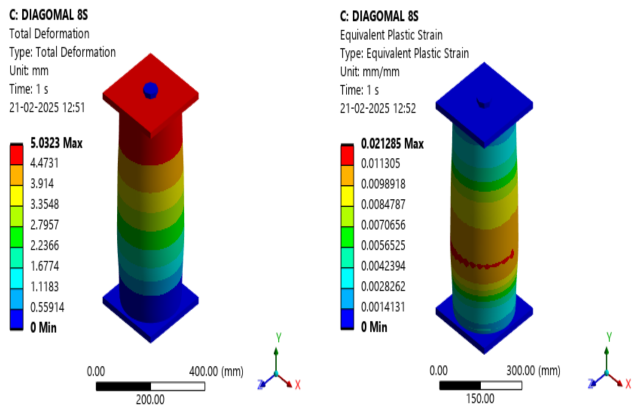

Fig-38: M3-2A EUFDSTCC with 8 Diagonal Stiffeners

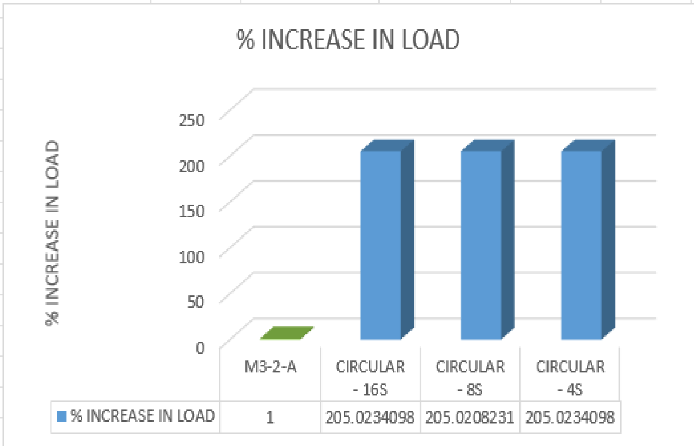

Fig-36: % Increase in Load chart

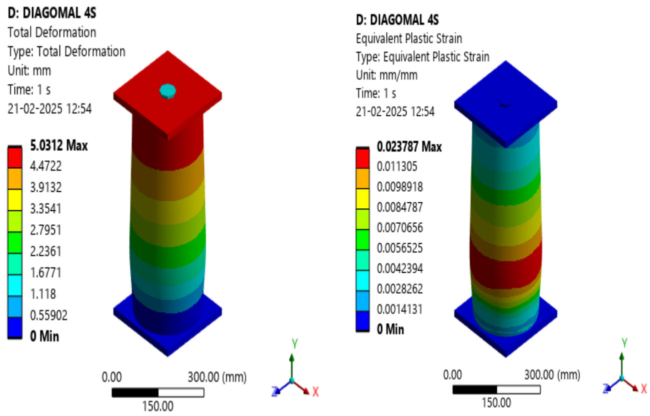

Fig-39: M3-2A EUFDSTCC with 4 Diagonal Stiffeners

5.2.3 Diagonal Stiffeners

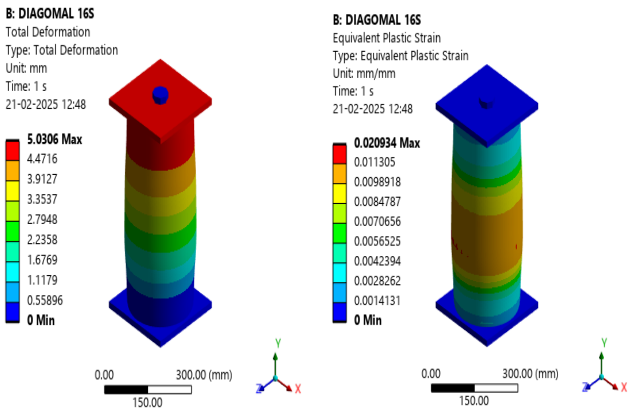

Fig-37: M3-2A EUFDSTCC with 16 Diagonal Stiffeners

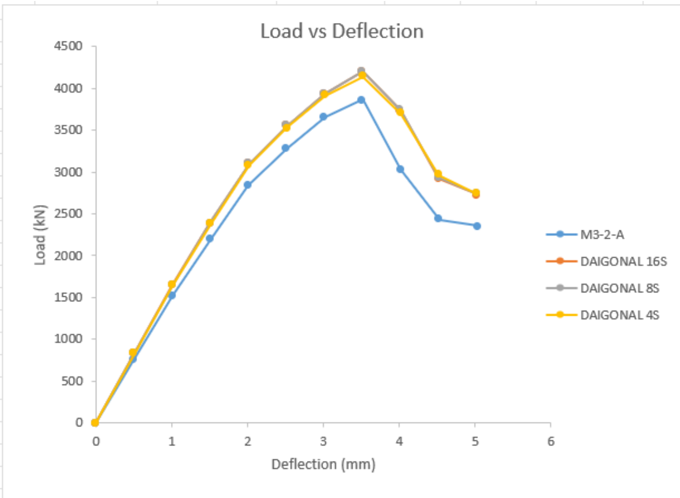

Fig-40: Load vs Deflection curve

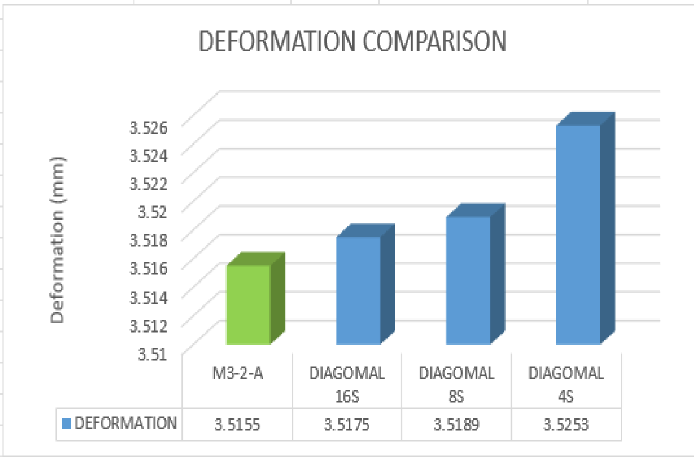

Fig-41: Deformation comparison chart

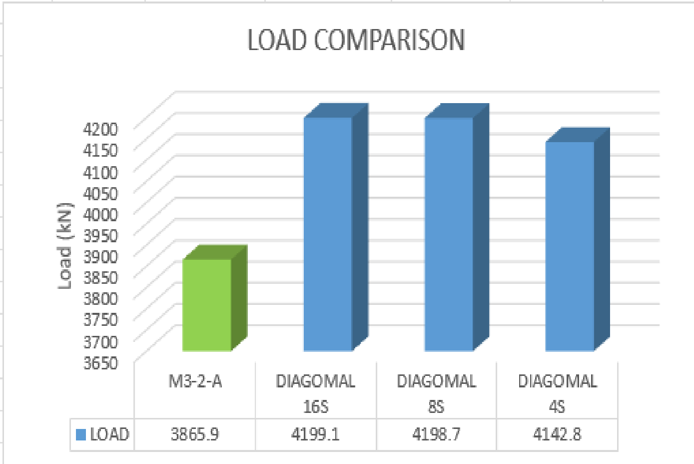

Fig-42: Load comparison chart

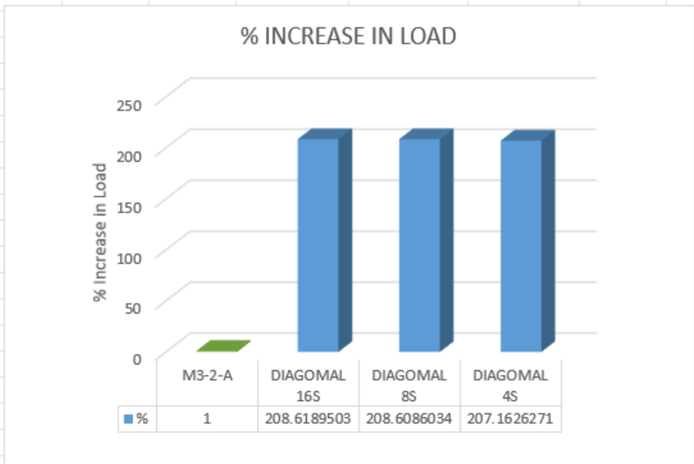

Fig-43: % Increase in Load chart

6. CONCLUSIONS

6.1 From the axial loading case

The analysis on the performance of Axially loaded EUFDST composite columns, it is determined that column models with larger inner tube diameter (d=168.3mm)(Models: M3-1-A, M6-1-A, M9-1-A) shows better performance when compared with column models with smaller inner tube diameter (d=60.3mm)(Models: M3-2-A, M6-2-A, M9-2-A), increasing the inner tube Diameter and it's thickness contributes more steel area and more volume of UHPC which performs the better axial strength and enough volume of ECC to withstand the tensile stress.

6.2 From the eccentric loading case

The analysis on the performance of Eccentrically loaded EUFDST composite columns, it is determined that column models with larger inner tube diameter (d=168.3mm)(Models: M3-1-E, M6-1-E, M9-1-E) shows better performance when compared with column models with smaller inner tube diameter (d=60.3mm)(Models: M3-2-E, M6-2-E, M9-2-E), increasing the inner tube Diameter and it's thickness contributes more steel area and more volume of UHPC which performs the better column strength and enough volume of ECC to withstand the tensile stress.

As the set of column models with λ=3 shows better performance than other models, the model M3-2-A has been taken as the representative model to incorporate stiffeners as its inner steel tube diameter is smaller and the space between two steel tubes facilitates the phenomenon.

6.3 Stiffeners in Double Steel Tubular Composite Columns

Vertical Stiffeners

The analysis on the performance of EUFDST composite columns with Vertical Stiffeners, it is determined that column IO-16S-M3-2A model shows better structural performance when compared with the other combinations of vertical stiffeners- IO-8S-M3-2A, IO-4S-M3-2A, I-8S-M3-2A, I-4S-M3-2A, O-8S-M3-2A, O-4S-M3-2A models, it shows less deformation and high load carrying capacity with more confinement property of 16 number of inner and outer stiffeners inside the column improves the overall structural performance.

Circular Stiffeners

The analysis on the performance of EUFDST composite columns with Circular Stiffeners, it is determined that column CIRCULAR-4S model shows better structural performance when compared with the other combinations of circular stiffeners- CIRCULAR - 16S, CIRCULAR - 8S models, it shows less deformation and high load carrying capacity with more confinement property of 4 number of stiffeners inside the column enhances overall structural performance.

Since the behaviour of CIRCULAR 16-S and CIRCULAR 4-S models are same, both options have the same total cross-sectional area of 1200 mm², meaning the material usage is identical.

However, economy also depends on factors like fabrication, welding, and structural efficiency:

- 16 stiffeners of 2.5 mm thickness might involve more cutting, handling, and welding, increasing labour costs.
- 4 stiffeners of 10 mm thickness requires fewer stiffeners, meaning less welding and fabrication time, making it more economical in practical terms.

Hence CIRCULAR-4S model is likely more economical due to reduced labour and fabrication efforts.

Diagonal Stiffeners

The analysis on the performance of EUFDST composite columns with Diagonal Stiffeners, it is determined that column DIAGONAL 16S model shows better structural performance when compared with the other combinations of diagonal stiffeners- DIAGONAL 8S, DIAGONAL 4S models, it shows less deformation and high load carrying capacity with more confinement property of 16 number of stiffeners inside the column increases overall structural performance.

The analysis on the ECC and UHPC Filled Double Steel Tubular Composite Columns with (Vertical, Circular and Diagonal) Stiffeners, the column with Vertical stiffeners shows better performance than other models.

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