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JOINT ANALYSIS OF STEEL BEAM-CFST COLUMNS CONFINED WITH CFRP BELT AND REBAR EMPLOYING FINITE ELEMENT METHOD

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Abstract: Concrete-filled steel tubes (CFST) are gaining prominence in the construction industry due to their numerous advantages over reinforced concrete columns (RCC). A CFST column consists of a steel conduit filled with concrete. The steel tube is the primary source of strength and rigidity, while the interior concrete provides additional compressive strength and fire resistance. CFST columns outperform reinforced concrete columns in terms of strength-to-weight ratio, deformability, fire resistance, enhanced construction efficiency, reduced dimensions, and environmental performance. For structures that require high strength, durability, and fire resistance, architects and engineers' favour CFST columns. CFRP is a composite material composed of carbon filaments and a polymer matrix based on epoxy. CFRP is a high-strength and

-rigidity material widely employed in the aerospace, automotive, and sports industries. This paper focuses on using carbon fibre-reinforced plastic (CFRP) as a joint belt and rebar in a Square Steel Beam- CFST Column connection system to increase the load-carrying capacity. This is accomplished by studying various belt layout arrangements and exploring different beam-column system configurations, which can be employed using Finite Element Analysis (FEA) and ANSYS software.

I. INTRODUCTION

Beam-column connections are important components of load-bearing structures in civil engineering. They are responsible for transferring loads from the beams to the columns, which then transfer the loads to the foundation. The design, detailing and construction of beam-column connections have a significant impact on the performance of a structure. Therefore, adequate attention must be given to these connections throughout the design and construction of the structure. Beam-column connections in reinforced concrete structures are often designed as moment connections. The purpose of moment connections is to transfer bending moments from the beam to the column. They are chosen instead of shear connections because they give a stiffer and stronger connection, resulting in higher structural performance. Depending on the extent of connection stiffness, moment connections are referred to as either full-strength or partial-strength. Full-strength connections are designed to transfer the maximum moment capacity of the beam to the column. They are often found in structures that require high stiffness and strength, such as high-rise buildings and bridges. In full-strength connections, the reinforcing steel of the beam is embedded in the column so that the beam and column behave as a single unit under load. In contrast, partial strength connections are designed to transfer some of the moment capacity of the beam to the column. They are used in low-rise buildings and parking garages that require moderate stiffness and strength. Bolts, plates or other fasteners are used to connect the beam and column in partial strength connections.

Beam-column connections require precise details to function properly. Proper design of the details ensures that the connection will withstand the loads and moments expected during the life of the structure. Reinforcing steel must be carefully placed and secured to resist the tensile and compressive forces transmitted through the connection. The geometry of the connection is another important consideration in the design of beam-column connections. The transfer of forces and moments between the beam and the column is determined by the geometry of the connection. Depending on the individual requirements of the structure, many different connection geometries are used. Common connection geometries include bolted end plate connectors, welded connections, and articulating connections. Beam- column connections must be designed and planned in detail, but construction quality monitoring is also important to ensure their performance. The construction process must ensure that the connection is built in accordance with the design and detail criteria. Reinforcing steel must be installed in accordance with the design, and appropriate concrete cover must be provided to prevent steel corrosion. Beam- column connections are key components of structures in civil engineering. Their design, details and construction must be carefully considered to ensure the safety, performance and durability of the structure. The connection type, geometry and details must be selected based on the individual requirements of the structure. Beam-column connections can ensure reliable and safe structural performance when properly designed, detailed and quality controlled. In this paper, square concrete-filled steel tubes (CFST) with CFRP reinforcement and CFRP belt in beam- column connection, strengthening methods and configurations are studied. Modelling and analysis are performed in the finite element software (FE) ANSYS 2021 R2.

II. OBJECTIVE AND SCOPE

A. Objective

The objective of this project aims to determine the appropriate arrangement for connecting beams and CFST columns using CFRP joint belt and rebar. It also aims to Compare the performance of steel and CFRP reinforcing bars in a beam-CFST column system. The final objective is to Analyze the performance of the CFST column concept in building interior and exterior location.

B. Scope

The study is limited to Square CFST columns with connections employing the belt and reinforcing bars made up of CFRP. The analysis is carried out using ANSYS software, along with the determination of belt layout.

III. REVIEW OF LITERATURE

The article by Junlong Yang et al. focused on the behaviour of circular columns made of carbon fibre-reinforced polymer (CFRP)-steel composite tubes and packed with strong concrete that has been eccentrically loaded. In this research, failure mechanisms and load versus mid-span lateral displacement curves of specimens under various test conditions in terms of depth are to be examined. The empirical findings suggest that different continuities of the outer steel tube significantly influence the failure patterns. At the specimens' 1/4 height, the concrete specimens were crushed and the steel tube was deformed on the compression side. These occurrences were clearly seen in samples having cracks on the exterior tube 25 mm away from the end plates. Local buckling was also seen towards the midpoint of the columns, where there were no holes in the steel tube.

The study titled "Seismic Behavior of a Novel Beam to Reinforced Concrete-Filled Steel Tube Column Joint" was published by Ben Mou et al. A series of experiments were conducted on four specimens consisting of beam-to-RCFST-column joints subjected to cyclic loading. Each specimen had a unique configuration of the middle steel tube and transfer sleeves, with some specimens including transfer sleeves and others not. With these experiments, researchers aimed to examine a variety of seismic indicators connected to the joint, such as failure processes, hysteretic performances, stiffness, deterioration, strength degradation, energy dissipation capacity, and strain responses. The primary objective of this study was to get a full understanding of the behavior exhibited by the newly developed beam-RCFST-column junction when subjected to seismic conditions. The investigated beam-to-RCFST-column junction exhibits observable hysteresis curves that indicate the presence of significant pressure issues resulting from the movement that takes place inside the transfer sleeve. The transfer sleeve plays a crucial role in determining the structural integrity of the investigated connection between the beam and the reinforced concrete-filled steel tube (RCFST) column. Finite Element Analysis (FEA) is a computational method that has shown the capacity to properly forecast mechanical properties and failure modes, while simultaneously providing a robust degree of reliability.

In 2015, QingJun Chen et al. released a study entitled "Axial Compressive Behaviour of Through-Beam Connections between Concrete-Filled Steel Tubular Columns and Reinforced Concrete Beams." The present research employs a reinforcing ring beam to expand the connection zone in order to offset any decrease in the axial load-carrying capacity caused by the discontinuity in the steel tube enveloping the column. The outcomes of two sequences of axial compression tests conducted on a total of 32 beam-column specimens are described. The axial load-carrying capacity of the connecting zone has been demonstrated to be significantly affected by the height and area ratio of the reinforcement in the ring beam. This study proposes a mathematical formula to estimate absolute compressive strength in axial direction of the connection under consideration. The calculation takes into account the effects of both local compression and confinement brought on by the presence of several layers of ring bars.

The paper by Yang et al. (2014) focused on the compressive behaviour of short columns made of high-strength concrete reinforced with circular tubed steel. This study involves the application of axial compressive stress to a set of 12 short columns composed the material known as high-strength concrete, often denoted as CTSRC,. The present research focused on many key aspects, includes the steel tube's yield strength, diameter to thickness, and ratio, the strength of the concrete, and the proportion of profile steel to steel. Numerous comprehensive research has been undertaken to analyze the failure processes, axial load-displacement curves, and maximum axial load capacities of Carbon Textile-Reinforced Cementitious (CTSRC) columns. The experimental results indicate that with the application of concentric tension, all specimens exhibited shear failure. The absence of consistent shear fractures over the whole perimeter of the structure may be ascribed to the presence of an internal steel profile inside the concrete. The inclusion of both a steel tube and profile steel inside the CTSRC columns resulted in a significant enhancement in the ultimate concrete strength and ductility. Consequently, this modification led to a substantial augmentation in the axial load-carrying capability of the columns.

The study conducted by Aboutaha, R. S. and colleagues in 2014 focuses on the seismic resistance of steel-tube high-strength reinforced concrete columns. In this work, six full-scale columns were exposed to consistent axial loads, cyclic lateral loads, and displacements. The experimental findings were compared to the outcomes of conventional high-strength reinforced-concrete columns. Based on the results obtained from this investigation, it has been determined that

STHSRC columns exhibit enhanced lateral strength and ductility compared to standard reinforced-concrete columns. The existence of axial compressive loads does not influence STHSRC columns' ductility compared to standard reinforced-concrete columns.
The publication by Liu et al. (2014) is entitled "Experimental and Numerical Studies of Reinforced Concrete Columns Confined by Circular Steel Tubes Exposed to Fire." The study proposed exposing four fully-scaled STCRC columns and one concrete-filled steel tubular (CFST) column to axial stress prior to their exposure to fire, eventually resulting in their structural failure. This research presents an analysis of the recorded furnace temperatures, specimen temperatures, graphs illustrating the temporal axial displacement, and the columns' firing resistance. The research used a nonlinear finite element model that included a sequential integration of temperature and stress analyses. The aforementioned model was used to do a comparison study in relation to fire experiments that had been previously performed on STCRC and CFST columns.

IV. METHODOLOGY

The primary objective of this research is to do a comprehensive examination of the existing body of literature with the intention of investigating the characteristics and efficacy of square and round concrete-filled steel tube (CFST) columns. Numerous scholarly investigations have examined square and circular concrete-filled steel tubes' structural characteristics and other parametric attributes (CFST). The project work is validated using the experimental findings of the most significant load-carrying capacity test received from the journal. The joint jacket demonstrates a maximum load-carrying value of 191kN. The result is compared with the result produced via ANSYS software, and the resulting percentage deviation is computed. This study uses ANSYS finite element software to simulate the connection between a Square Concrete Filled Steel Tube column and a Steel beam, including a CFRP joint belt and rebar. The research combines concrete and diverse steel standards in various configurations. The use of carbon fibre-reinforced polymer (CFRP) belts in the form of connecting jackets is utilized to augment the structural integrity of the column. The geometric features of the structural components used in this investigation are shown in Table 1.

Table -1: Geometrical properties of the structural components

Table -1.1:

Component	Dimension
Concrete square column	Side = 265.86 mm Total height = 2330 mm
Steel tube	Thickness = 2 mm
Beam I section	Beam height = 270 mm Beam width = 175 mm Web thickness = 8 mm Flange thickness = 10 mm Total length = 3000 mm
Jacket	Height = 270 mm Thickness = 6 mm
Rebar	Diameter = 18 mm No: = 12
Concrete	Density = 2300 kg/m^3 Youngs modulus = 33 MPa Poisson’s ratio = 0.18 Yield strength = 40 MPa

CFRP	Youngs Modulus = 240 GPa Poisson's ratio = 0.2 Ultimate strength = 3800 MPa Density = 1.7 g/ cm^3

Table -1.2:

Steel	Beam flange: Yield strength = 298 MPa Ultimate strength = 438 MPa Poisson's ratio = 0.3 Youngs Modulus = 200 GPa
	Beam web: Yield strength = 410 MPa Ultimate strength = 557 MPa Poisson's ratio = 0.3 Youngs Modulus = 200 GPa
	Steel tube: Yield strength = 320 MPa Ultimate strength = 455 MPa Poisson's ratio = 0.3 Youngs Modulus = 200 GPa
	Jacket: Yield strength = 351 MPa Ultimate strength = 505 MPa Poisson's ratio = 0.3 Youngs Modulus = 200 GPa
	Steel rebar: Yield strength = 543 MPa Ultimate strength = 676 MPa Poisson's ratio = .3 Youngs Modulus = 200 GPa

The total lengths of the column and beam are 2330mm and 3000mm, respectively. Concrete is modelled using SOLID65 elements, whereas steel tubes, jackets, CFRP belts, and beam configurations are modelled using SHELL186 elements. The element type LINEBODY188 is used to represent rebars. Fig 1 shows the modelling the structural system

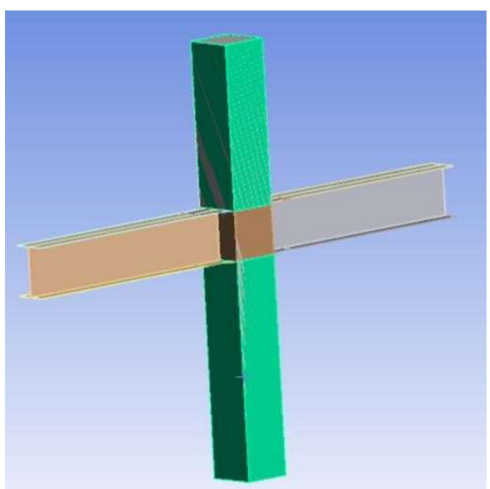

Fig 1: model of the steel beam- CFST column connection system

The square CFST column-Steel Beam connection system is modelled using hexahedral mesh, which is a 4-noded mesh. Meshing is done using a programme modulated coarse mesh with a mesh size of 60mm. Load is applied as a force of 1187 kN, Fig 2 [1] shows the boundary conditions given to execute the analysis.

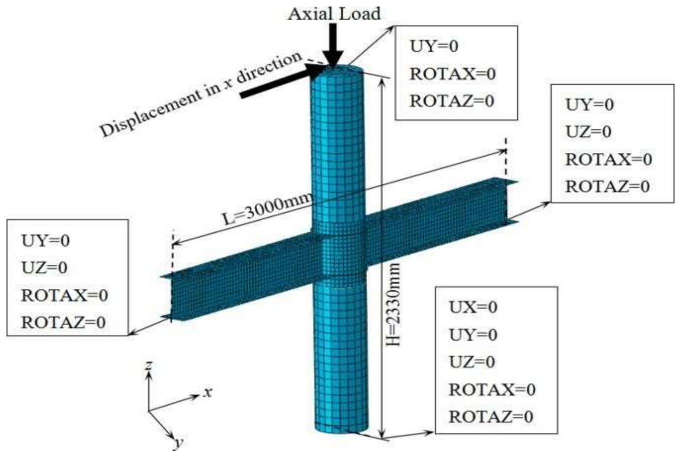

Fig 2: Boundary Conditions

The primary investigation is on establishing a correlation between a Concrete Filled Steel Tube Square Column and a Steel Beam. Multiple layouts of CFRP belts at the connection, together with CFRP rebar, are examined to identify the optimal configuration for enhancing the load bearing capability of the aforementioned system. ANSYS software is used to construct nine CFRP belt layouts, including full CFRP rebar with three distinct types of classification profiles for the CFRP belt provided at the connection. The classifications are based on thickness, number of layers and number of divisions of the belt. Table 2 shows the name of the specimens based on the classification.

Table -2: Specimen names Table -2.1:

Based on Thickness	
CFRP T1	CFRP belt with thickness of 1 mm
CFRP T2	CFRP belt with thickness of 2 mm
CFRP T3	CFRP belt with thickness of 3 mm
CFRP T4	CFRP belt with thickness of 4 mm

Table -2.2:

Based on Number of Layers	
CFRP T2	CFRP belt containing 1 layer
CFRP T2L2	CFRP belt containing 2 layers
CFRP T2L3	CFRP belt containing 3 layers
CFRP T2L4	CFRP belt containing 4 layers

Table -2.3:

Based on Belt Division	
CFRP T2L2	CFRP belt with no division
CFRP T2L2D2	CFRP belt divided into 2 belts

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CFRP T2L2D3	CFRP belt divided into 3 belts

Square CFST column- Steel beam connection is modelled in ANSYS software with different belt layout using CFRP at the connection joint. Fig 3,4,5 shows the belt, belt divided into two and belt divided into three.

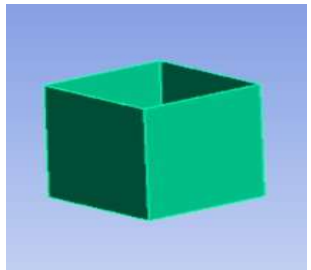

Fig 3: CFRP belt

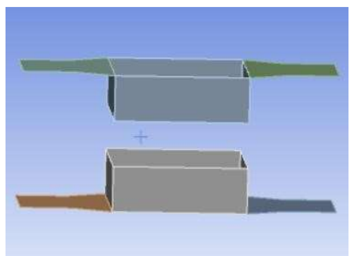

Fig 4: Belt division into two

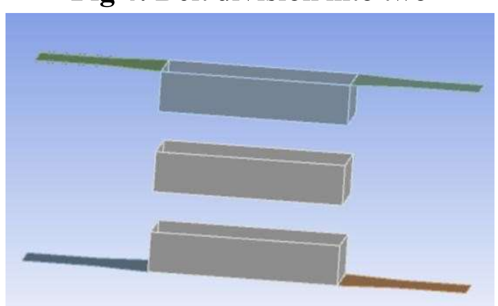

Fig 5: Belt division into three

The concert of the CFST Column-steel beam connection is analyzed using several configurations of CFRP belt with CFRP rebar. ANSYS software is used for nonlinear static structure analysis. The load carrying capacity is investigated. Stress diagram is obtained after analysis. Fig 6,7 shows the load-displacement graph and equivalent stress of CFRP T2.

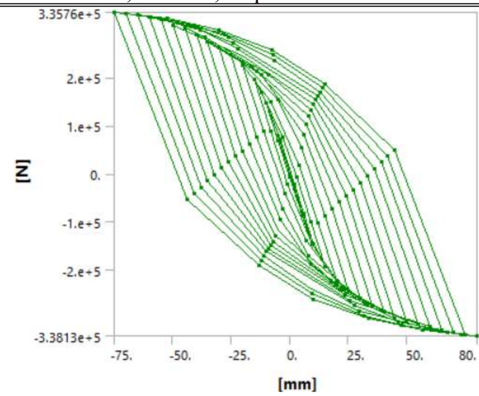

Fig 6: load- Displacement graph

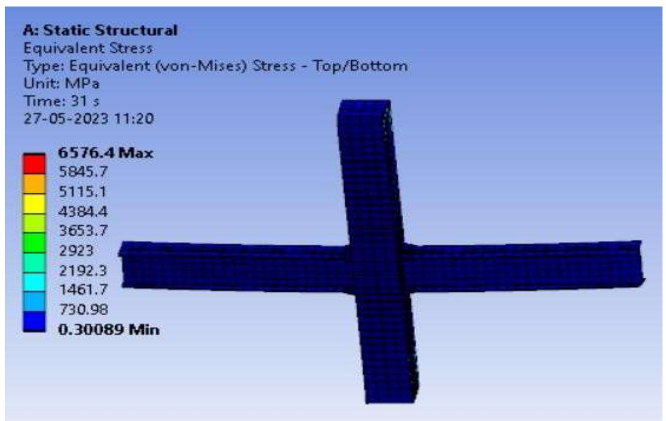

Fig 7: Equivalent Stress

Furthermore, analysis is conducted on the performance of the suitable belt layout system being CFRPT2L2 with CFRP as rebar and steel as rebar. The modelling, analysis, and comparison of two structural configurations, the first of which uses CFRP as rebar and the second of which employs steel as rebar.

The performance of the novel adopted connection mechanism in the CFST square column-steel beam joint using CFRP rods as rebar as well as steel rods as rebar is studied. ANSYS software is used for nonlinear statics structure analysis. Both systems' deformation, load carrying capacity, equivalent stress, and strain energy are investigated. Fig 8,9,10,11 depicts the obtained diagrams.

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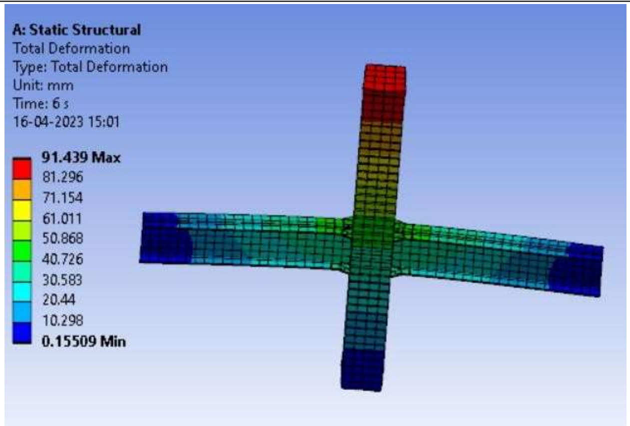

Fig 8: CFRP T2L2FS

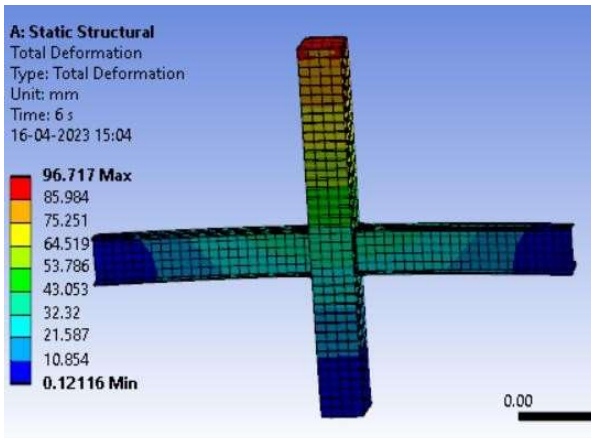

Fig 9: CFRP T2L2FC

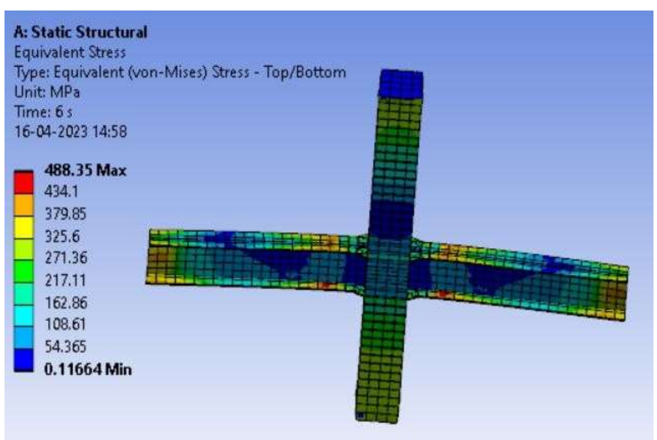

Fig 10: CFRP T2L2FS

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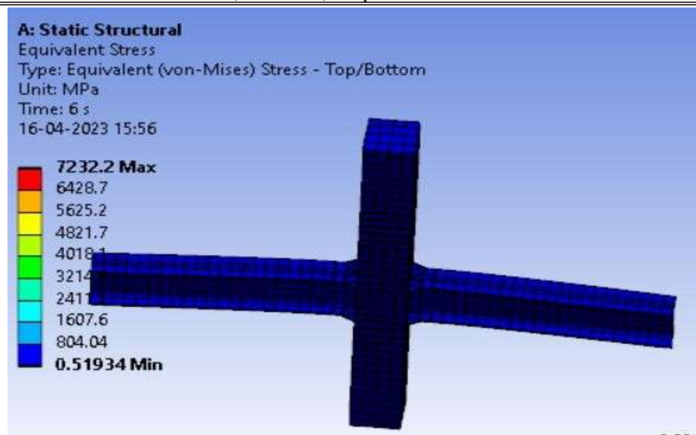


Fig 11: CFRP T2L2FC

Modelling of CFST columns with (a) three beams attached to a single column with put forth joint connection (b) four beams attached to a single column with proposed joint connect is performed. Fig 12,13 shows the model of 3 beam- column system and 4 beam-column system.

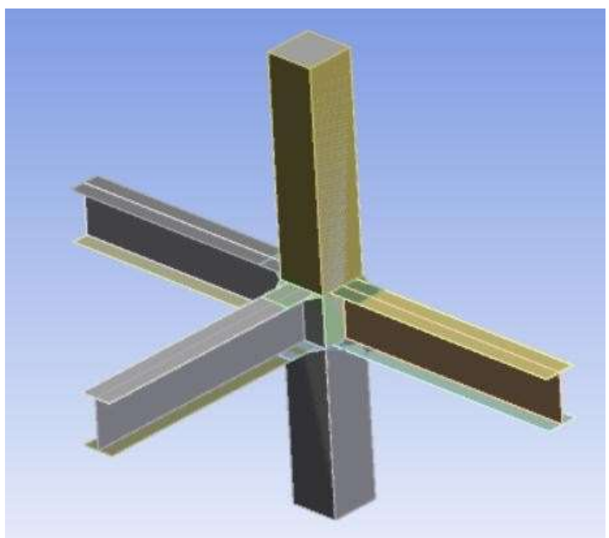


Fig 12: 3 Beam-Column system

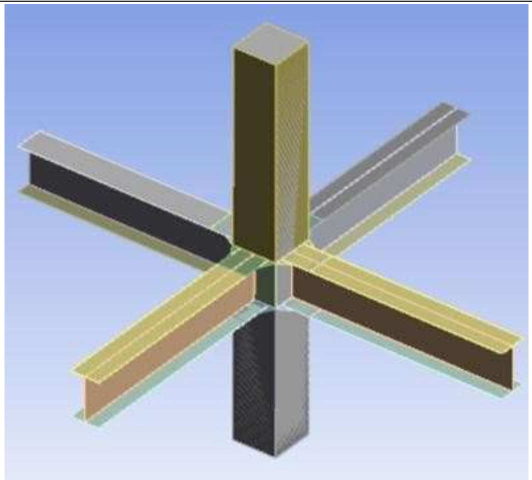


Fig 13: 4 Beam-Column system

The efficacy of the connection between concrete-filled steel tubes and steel beams is evaluated under different layouts of the same. A corner column system with three beams connected to a single column and an inside column with four beams connected to a single standing vertical load bearing structural element are developed and examined. ANSYS software is used to do nonlinear static structural analysis. Deformation and load bearing capability are investigated. Fig14,15 shows column specimen deformation graphs and equivalent stress diagrams

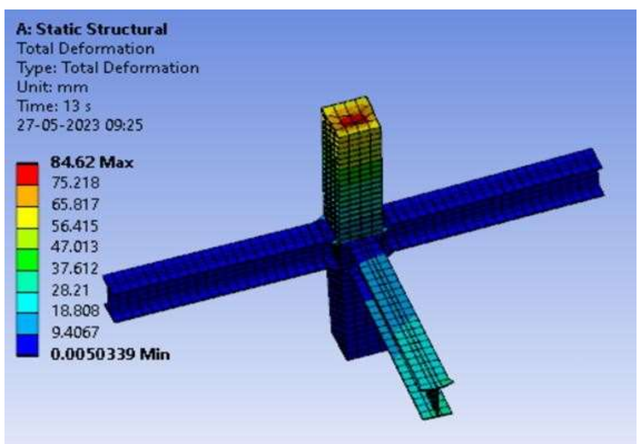


Fig 14 a: CFST Column –3 Beam system Deformation Graph

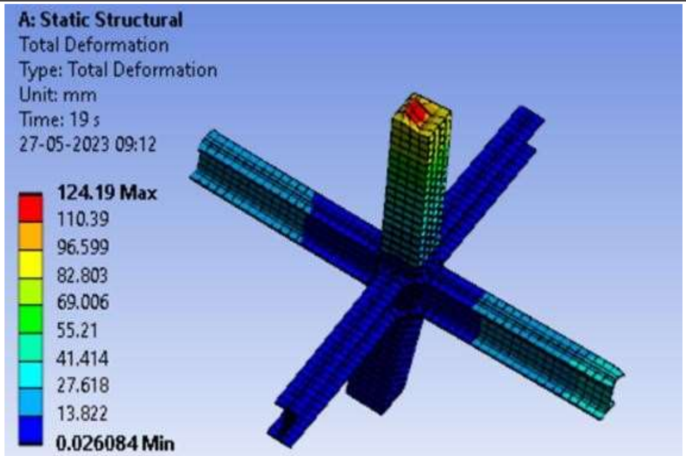


Fig 14 b: CFST Column –4 Beam system Deformation Graph

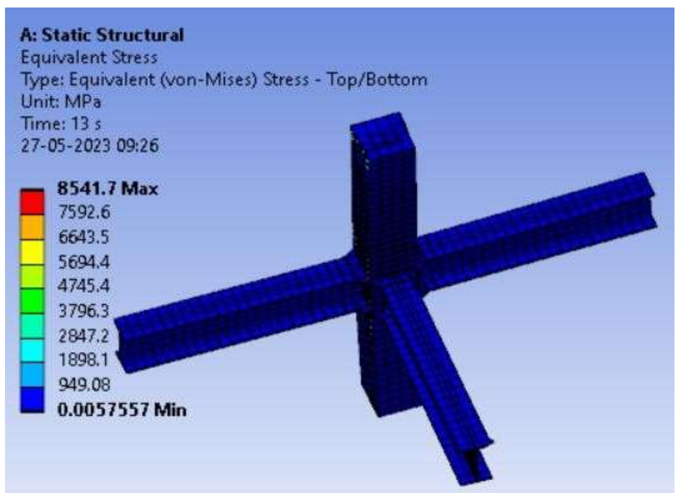


Fig 15 a: CFST Column –3 Beam system Equivalent Stress Graph

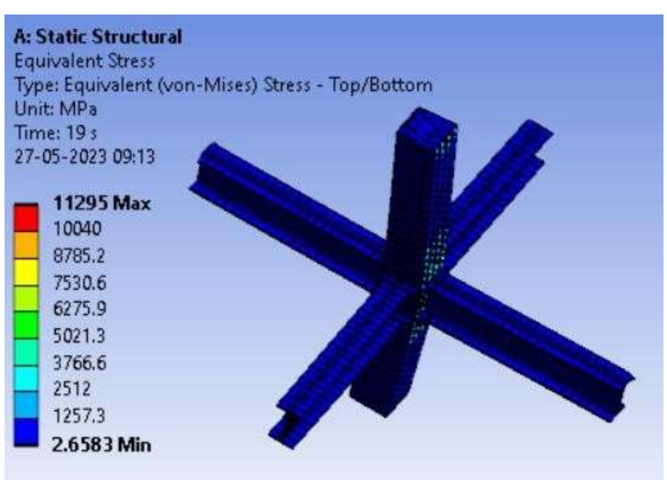


Fig 15 b: CFST Column –4 Beam system Equivalent Stress Graph

V. RESULT AND DISCUSSION

The result of nonlinear static structural analysis of different configurations of CFRP belt with CFRP reinforcement bars used in the square CFST column- steel beam led to a combination of the belt elements that provides maximum load-carrying capacity. Load deformation curve is taken for each model and the system provided maximum value was selected. The Table 3 shows the load and deflection of the structural system for the different classification of the belt layout.

Table -3: Results after the analysis of classification of belt layout

Table -3.1: Based on thickness

Specimen name	Thickness (mm)	Peak load (KN)	Equivalent Stress (MPa)	Peak Load difference
CFRP T1	1	337.12	6589.3	1.01
CFRP T2	2	338.130	6567.4	0.97
CFRP T3	3	337.160	6522.4	0.06
CFRP T4	4	337.100	6519.9	

Table 3.2: Based on number of Layers

Specimen name	No: of Layers	Peak load (KN)	Equivalent Stress (MPa)	Peak Load difference
CFRP T2	1	338.130	6567.4	0.47
CFRP T2L2	2	338.600	6523.5	0.21
CFRP T2L3	3	338.810	6529.7	0.08
CFRP T2L4	4	338.890	6514	

Table 3.3: Based on number of Belt Division

Specimen name	No: of belts	Peak load (KN)	Equivalent Stress (MPa)	Peak Load difference
CFRP T2L2	1	338.600	6523.5	5.13
CFRP T2L2D2	2	333.47	6738.5	4.79
CFRP T2L2D3	3	338.26	6581.4	

From this analysis it was found that maximum load carrying capacity in the case of thickness was achieved for CFRP T2 with a value of 338.10 kN, CFRP T3 showed a decrease in the loading capacity to a 0.28% percentage. Considering the next configuration being the number of layers, the maximum load carrying capacity was achieved for CFRP T2L4 having a value of 338.890 kN.The peak load difference was higher when the configuration changed from CFRP T2 to CFRP

T2L2 being 0.47.There is a gradual increase in the loading carrying capacity throughout the increasing of number of layers In the case of belt division, the value obtained for load carrying capacity for CFRP T2L2D3 is 338.26 kN and that of CFRP T2L2 is 338.60 kN . The peak load difference for the case of no division of the belt to division by two the value obtained is 5.13. The load carrying capacity decreased for the mentioned to a percentage of 1.53%. The overall increase in the strength of the in comparison to the reference journal system was 77.21%.

In the case of analysis of the suitable belt layout system with CFRP as rebar as well as steel as rebar, the load deflection curves obtained in both cases are compared. The chart1,2 below shows the load -deformation graph and energy absorption of the proposed two system.

Chart 1: Load Deflection Comparison of Rebar

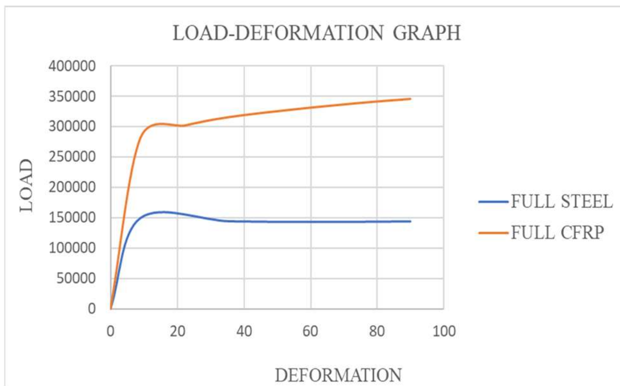
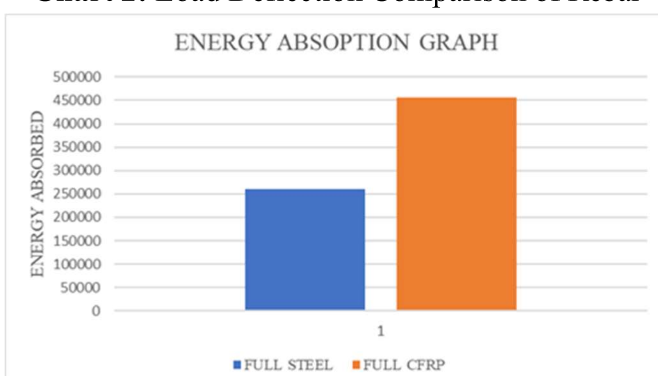


Chart 2: Load Deflection Comparison of Rebar



The load-deformation diagram shows that the CFRP shows more stiffness when compared to steel rebar as plasticity starts after the deformation value reaches 8 mm in the case of steel while for CFRP till starts after 11 mm. The maximum displacement allowed during the analysis is 90 mm. Steel shows a deformation of 91.69 mm while CFRP shows deformation of 96.71 mm. After studying the load- deformation graph the failure for steel starts when the deformation values exceed 22 mm, while in the case of CFRP, it is after 35 mm that the failure starts. In the case of energy absorption, CFRP shows higher value when compared to Steel with 74.57% increase.

The comparison of load and deflection of CFST columns with interior and exterior beam system employing novel CFRP joint belt and CFRP rebar are in given Table 4. Chart 3,4,5 shows the load deflection, load carrying capacity and energy absorption comparisons of the two systems we have adopted.

Table 4: Load-deflection comparison

Models	Load (kN)	Deflection (mm)
3 beam-column system	859.44	70
4 beam-column system	1008	70

Chart 3: Load Deflection Comparison of 3 beam – column system and 4 beam – column system

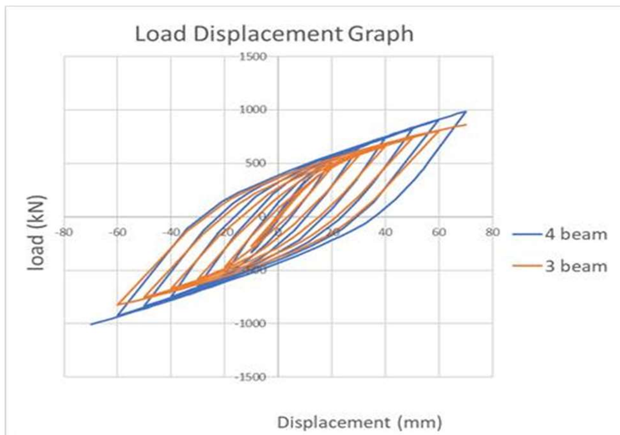


Chart 4: Load Carrying capacity Comparison of 3 beam – column system and 4 beam – column system

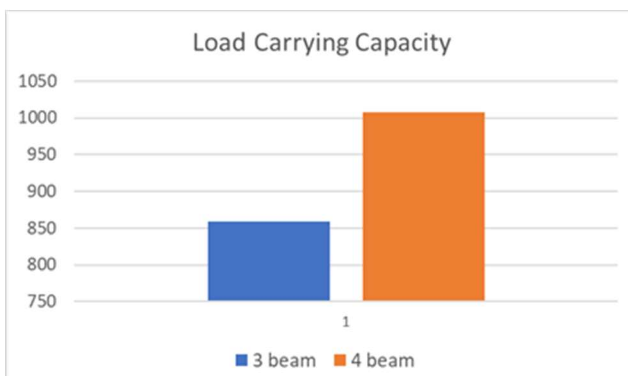
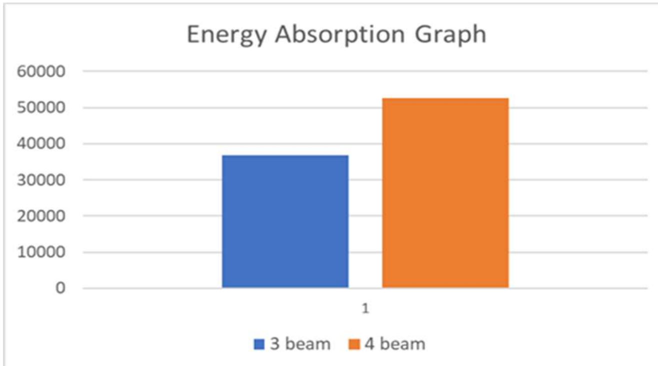


Chart 5: Load Carrying capacity Comparison of 3 beam – column system and 4 beam – column system



Load Carrying capacity increases as the number of support reaction increases with a maximum value of 1008 kN achieved for 4 beam-column connection. The energy absorption value increases as the number of beams joining the column increases. Deformation and Stresses increases with the number of beams attached to the column with maximum value for 4 beams being 124.19 mm and 11295 MPa respectively. The calculated Energy absorption graph showed that the 4 beam-column system showed a increased absorption rate of 42.26% when in comparison to the 3 beam – column joint system.

VI. CONCLUSION

Square CFST column- steel beam joint connection containing CFRP belt and rebar patterns are modelled and analyzed

- It was found that the use of CFRP as belt in the jacket and as rebar showed a significant increase in the load carrying capacity of beam- column system by 77.27%
- Optimum thickness was found to be 2 mm and the optimum number of layers was found to be 2 with a peak load difference of 1.01
- Full CFRP belt of thickness 2 and layer number 4 showed higher load carrying capacity with a value of 338.890 kN but considering peak load difference being greater when layer number was increased to 2 with a value of 0.47, CFRPT2L2 was adopted.
- Nomenclature of the suitable economical belt layout is CFRPT2L2D3 with a load carrying capacity of 338.26 kN but CFRPT2L2 was approved for further analysis for having the maximum load carrying capacity of 338.600 kN in comparison
- CFRP rebar has a higher modulus of elasticity than steel rebar which means it can resist deformation under stress to a greater extent than steel this property can lead to an increase in its load carrying capacity as compared to steel rebar which showed only a load carrying capacity of 147.70kN. Energy absorption also increased by 74.57% when CFRP was used as a rebar.
- Energy absorption rises when support responses increase, and this may be attributed to an extra load route for distributing and dissipating energy during seismic or other loading circumstances

in the case of a four beam-column system with 42.26% increase in comparison to 3 beam-column system. It should also be noted that the additional beam in this system adds redundancy to the system. As a result, the overall resilience and capacity of the connection enhances with an increase of 23.138% in case of 4 beam- column system.

- It is observed that with a suitable configuration of the steel beam- CFST square column joint connection confined with CFRP belt and CFRP rebar, square column can achieve a higher load carrying capacity in comparison with a circular column of the same volume as we obtained 338.600 kN

VII. FUTURE SCOPE

New innovative materials can be discovered and studies can be conducted on their engineering properties so as to carry out researches on improving the strength and durability of a structural element employing these new materials.

Materials that can be economically adopted in conditions of uncontrolled and unpredicted force application can be studied. Different configurations and layout of the beam- column system can be explored and researched upon for square columns and ways to improve their strength in comparison to circular columns.

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