# FINITE ELEMENT ANALYSIS OF STEEL BEAM-CFST COLUMN JOINTS CONFINED WITH CFRP BELT AND REBAR

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**Abstract -** *Concrete-filled steel tube (CFST) is becoming increasingly popular in the construction industry due to their numerous advantages over reinforced concrete columns (RCC). A CFST column consists of a steel tube filled with concrete. The main strength and stiffness are provided by the steel tube, while the concrete core provides additional compressive strength and fire resistance. CFST columns outperform reinforced concrete columns in terms of strength-to-weight ratio, deformability, fire resistance, improved construction efficiency, lower dimensions, and environmental performance. CFST columns are preferred by architects and engineers for structures that require high strength, durability and fire resistance. CFRP is a composite material composed of carbon fibers and a polymer matrix, usually epoxy. CFRP is a material with high strength and stiffness that is extensively utilized in aerospace, automotive and sports applications. This paper focuses on using CFRP as a joint belt as well as rebar in a Square Steel Beam- CFST Column connection system to improve the load carrying capacity by studying various arrangement of the belt layout and explores different configuration of the beam column system where they can be employed through Finite Element Analysis (FEA) with the help of ANSYS software.*

***Key Words***: CFST column, Steel Beam, CFRP, Connection system, Finite Element Analysis, 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

Junlong Yang et al. published a paper on Behaviour of eccentrically loaded circular CFRP-steel composite tubed steel-reinforced high-strength concrete columns. In this paper, The failure modes and load versus mid-span lateral displacement curves for specimens with various test parameters were thoroughly examined. The findings of the experiments reveal that the varying continuities of the exterior steel tube have a significant impact on failure patterns. Crushing of concrete and bulging of the steel tube in the compression side arose near the 1/4 height of the specimens with grooves 25 mm away from the end plates on the external tube, whereas local buckling was observed around the mid-height of the columns with no gaps on the steel tube.

Ben Mou et al. published a paper on Seismic behaviour of a novel beam to reinforced concrete-filled steel tube column joint This study deals with Four beam-to-RCFST-column specimens were tested under cyclic loading, each with a different cross-section of middle steel tube and transfer sleeves (with or without) to clarify the main seismic indicators, such as failure modes, hysteretic performances, stiffness, degradation, strength degradation, energy dissipation capacity, and strain responses of the novel beam-RCFST-column joint. Because of the slip around the transfer sleeve, the hysteretic curves of the tested beam-to-RCFST-column joint display apparent pinch phenomena. The transfer sleeve is the most important component influencing the strength of the tested beam-to-RCFST-column junction. Mechanical parameters and failure modes are reliably predicted by the FEA.

QingJun Chen et al. (2015) presented a paper on Axial Compressive Behaviour of Through-Beam Connections between Concrete-Filled Steel Tubular Columns and Reinforced Concrete Beams. In this study A reinforcing ring beam is used to increase the connection zone in order to account for any decrease in axial load-carrying capability caused by the discontinuity in the steel tube that encases the column. The results of two sets of axial compressive testing on 32 beam-column specimens are given. The height and area ratio of the reinforcement in the ring beam are found to have a considerable influence on the axial load-carrying capacity of the connecting zone. A formula for predicting the final axial compressive strength of this connection is provided, taking into account the confinement induced by numerous layers of ring bars and the influence of local compression.

Junlong Yang et al. (2014) presented a paper on Compressive Behaviour of Circular Tubed Steel-Reinforced High-Strength Concrete Short Columns . In this study total of 12 (CTSRC) short columns made with high-strength concrete are tested under axial compressive stress. The key variables of the test are the diameter-to-thickness ratio and yield strength of the steel tube, concrete strength, and profile steel steel ratio. The failure modes, axial load-displacement curves, and ultimate axial load of CTSRC columns are all thoroughly examined. According to the test results, all specimens exhibited shear failure under concentric loading. Because of the existence of internal profile steel, the shear cracks around the concrete perimeter were not connected throughout the entire length. The CTSRC columns' ultimate concrete strength and ductility were greatly improved as a result of the double confinement given by the steel tube and profile steel, resulting in a significant improvement in axial capacity.

R. S. Aboutaha et al. (2014) presented a paper on Seismic Resistance Of

Steel-Tubed High-Strength Reinforced-Concrete Columns. In this paper Six full-scale columns were tested experimentally under constant axial loads and cyclic lateral load/displacement. The findings of the tests were compared to those of regular high-strength reinforced-concrete columns. According to the findings of this study, STHSRC columns have more lateral strength and ductility than regular reinforced-concrete columns. The ductility of STHSRC columns is not affected by the presence of axial compressive loads when compared to regular reinforced-concrete columns.

Faqi Liu et al. (2014) published a paper on Experimental and Numerical Studies of Reinforced Concrete Columns Confined by Circular Steel Tubes Exposed to Fire . This study proposed Four full-scale STCRC columns and one concrete-filled steel tubular (CFST) column were axially loaded before being exposed to fire until they failed. The columns' measured furnace temperatures, specimen temperatures, axial displacement against time graphs, and fire resistance are given and discussed. The model was then evaluated against recent fire tests on STCRC and CFST columns published in the literature using a nonlinear finite-element model with a sequentially coupled thermal-stress analysi

## IV. METHODOLOGY

A literature review is conducted on square and round CFST columns. Several studies have been conducted to investigate the structural behavior and other parametric properties of square and circular CFST. The experimental results of the highest load carrying capacity test from the journal are used to validate the project work and the maximum load carrying value obtained for the joint jacket is 191kN. The result is compared with the result obtained in ANSYS software and the resulting percentage deviation is calculated. In this paper, ANSYS finite element software is used to simulate Square Concrete Filled Steel Tube column- Steel beam connection with CFRP joint belt and rebar. The study makes use of design mix concrete and different steel specifications in various forms. To improve the structural performance, connection jackets with CFRP belts are used to reinforce the column. The Table 1 below shows the geometrical properties of the structural components that have been employed in this paper.

**Table -1: Geometrical properties of the structural components**

**Table -1.1:**

| Component | Dimension |
|---|---|
| Concrete square column | Side = 265.86 mm<br>Total height = 2330 mm |
| Steel tube | Thickness = 2 mm |
| Beam I section | Beam height = 270 mm<br>Beam width = 175 mm<br>Web thickness = 8 mm<br>Flange thickness = 10 mm<br>Total length = 3000 mm |
| Jacket | Height = 270 mm<br>Thickness = 6 mm |
| Rebar | Diameter = 18 mm<br>No: = 12 |
| Concrete | Density = 2300 kg/m$^3$<br>Youngs modulus = 33 MPa<br>Poisson's ratio = 0.18<br>Yield strength = 40 MPa |
| CFRP | Youngs Modulus = 240 GPa<br>Poisson's ratio = 0.2<br>Ultimate strength = 3800 MPa<br>Density = 1.7 g/ cm$^3$ |

**Table -1.2:**

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

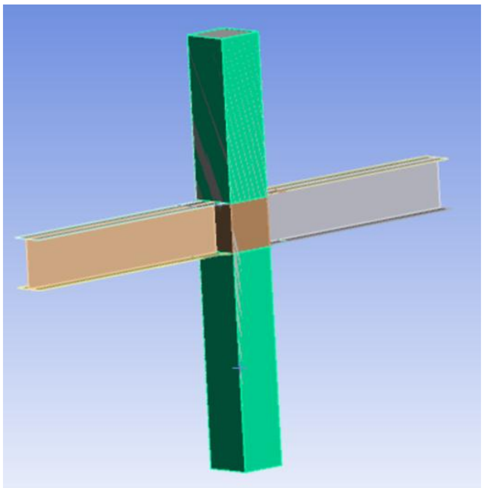


**Fig 1:** model of the steel beam- CFST column connection system

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.

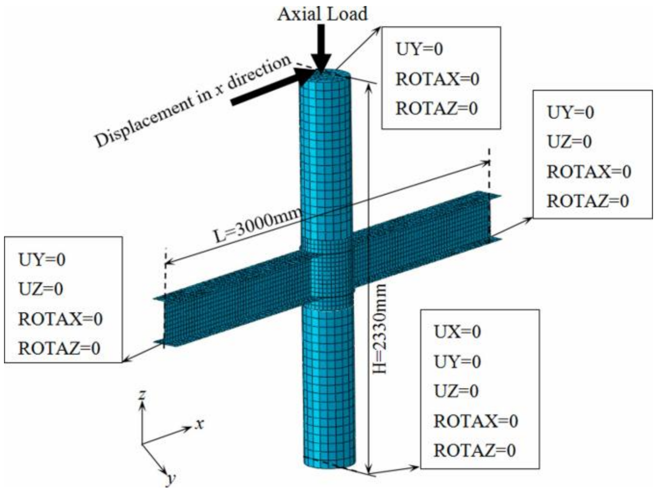



**Fig 2:** Boundary Conditions

The first analysis is based on a Concrete Filled Steel Tube Square Column - Steel Beam connection with multiple CFRP belt layouts at the connection and CFRP rebar to determine the best configuration for increasing the load carrying capacity of the aforesaid 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 |
| 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.

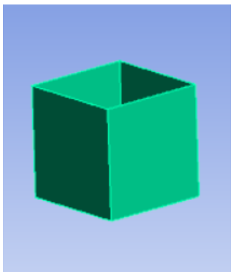


**Fig 3:** CFRP belt

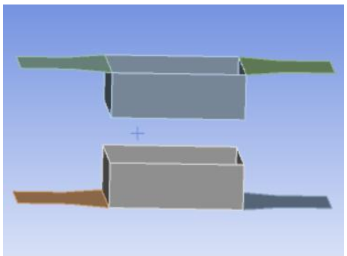


**Fig 4:** Belt division into two

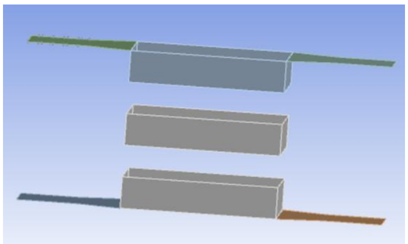


**Fig 5:** Belt division into three

The performance 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.

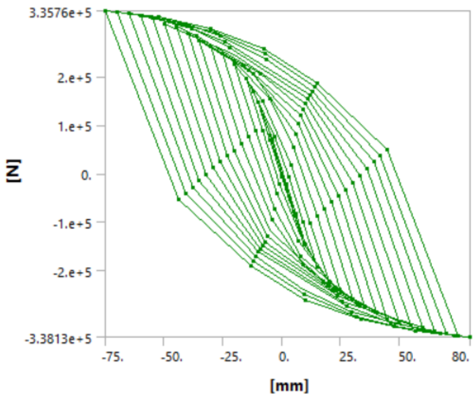



**Fig 6:** load- Displacement graph

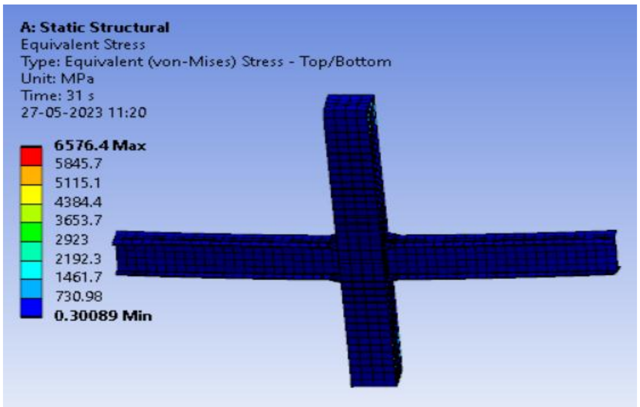



**Fig 7:** Equivalent Stress

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.

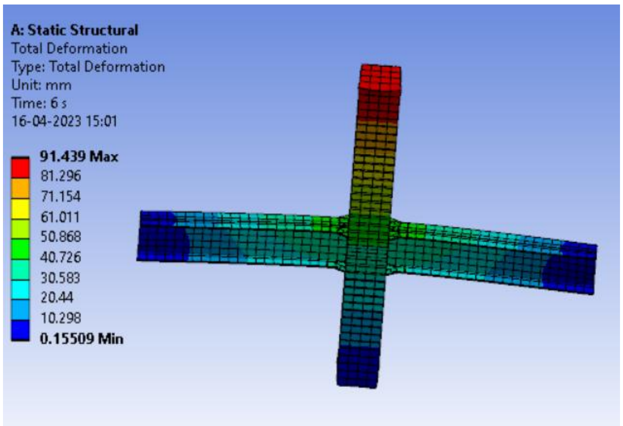



**Fig 8:** CFRP T2L2FS

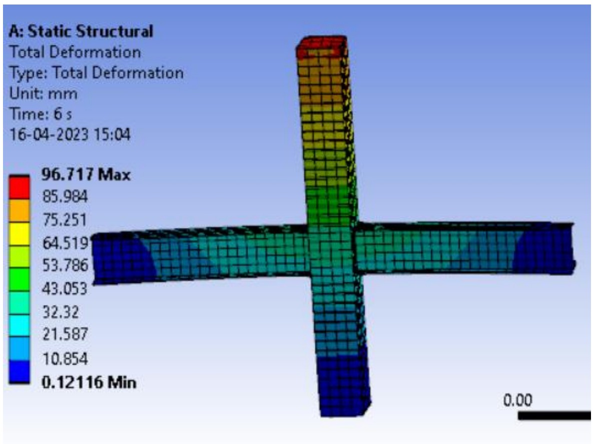



**Fig 9:** CFRP T2L2FC

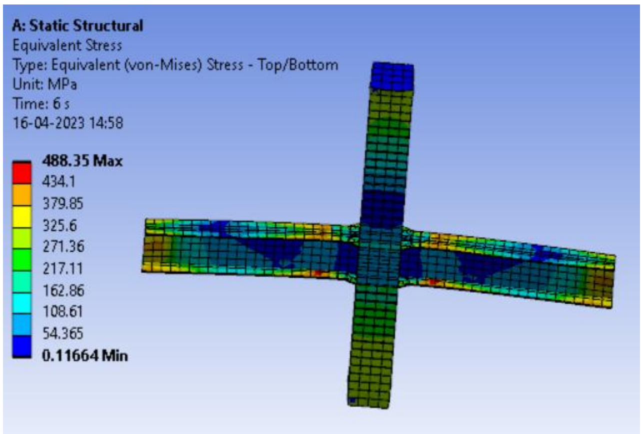



**Fig 10**: CFRP T2L2FS

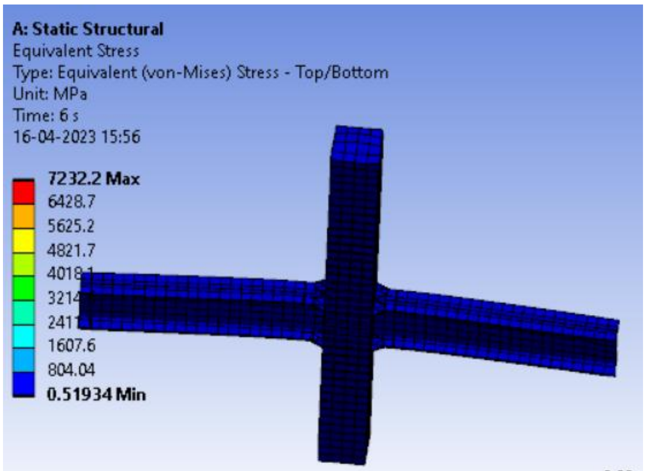



**Fig 11**: CFRP T2L2FC

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.

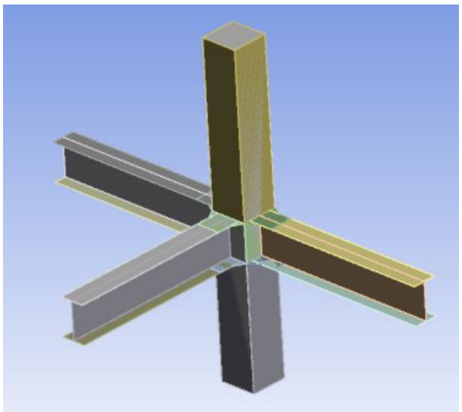


**Fig 12:** 3 Beam-Column system

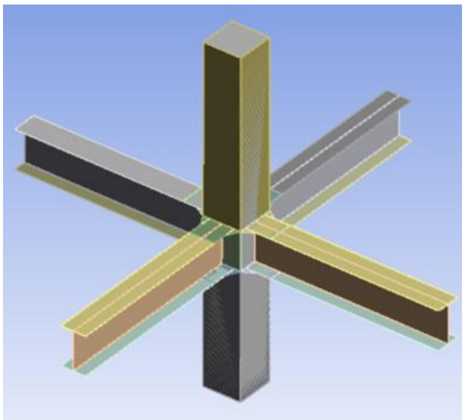


**Fig 13**: 4 Beam-Column system

The performance of Concrete Filled Steel Tubes-Steel Beam Connection is studied under different layouts of the same with the unique connection presented. 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

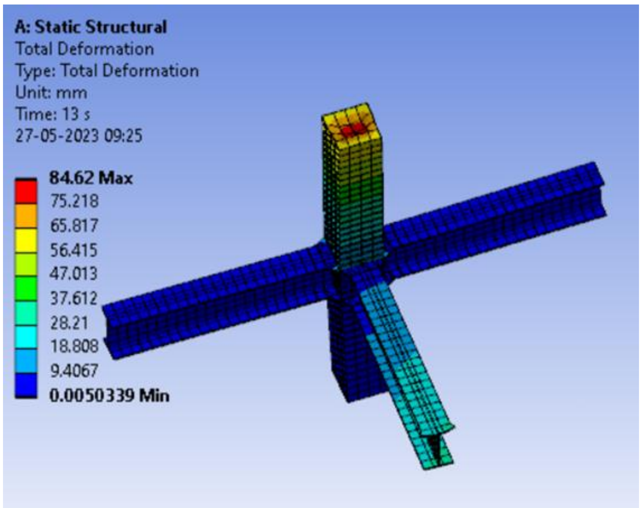



**Fig 14 a:** CFST Column –3 Beam system Deformation Graph

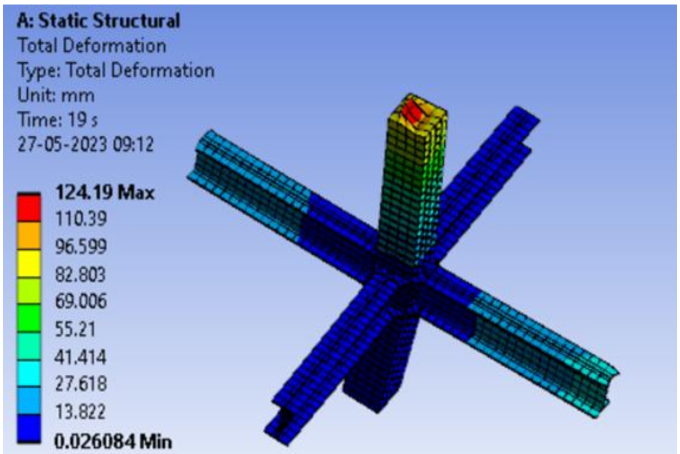



**Fig 14 b**: CFST Column –4 Beam system Deformation Graph

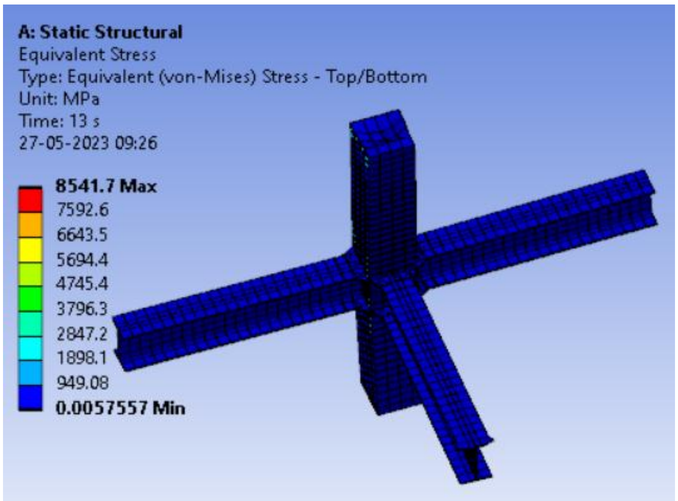



**Fig 15 a**: CFST Column –3 Beam system Equivalent Stress Graph

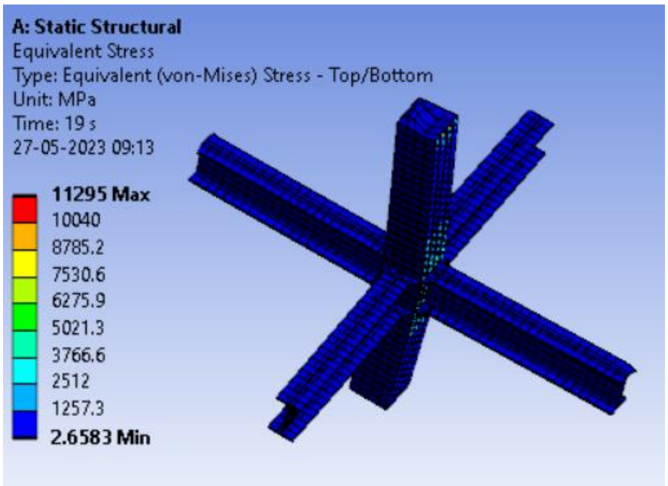



**Fig 15 b**: CFST Column –4 Beam system Equivalent Stress Graph

## 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

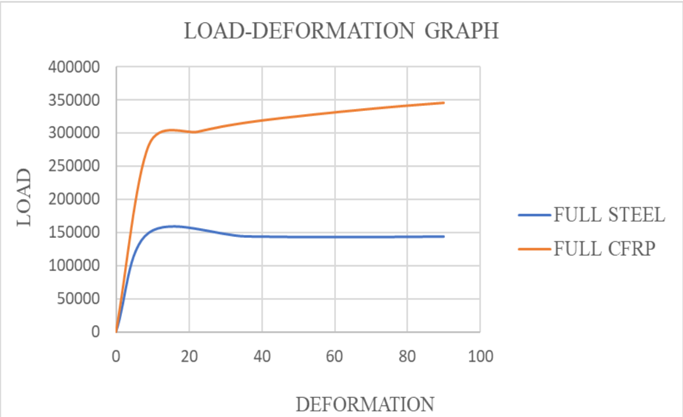
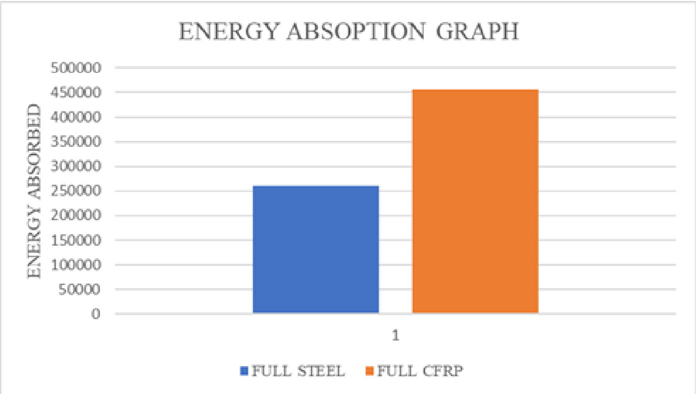



**Chart 2:** Load Deflection Comparison of Rebar




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

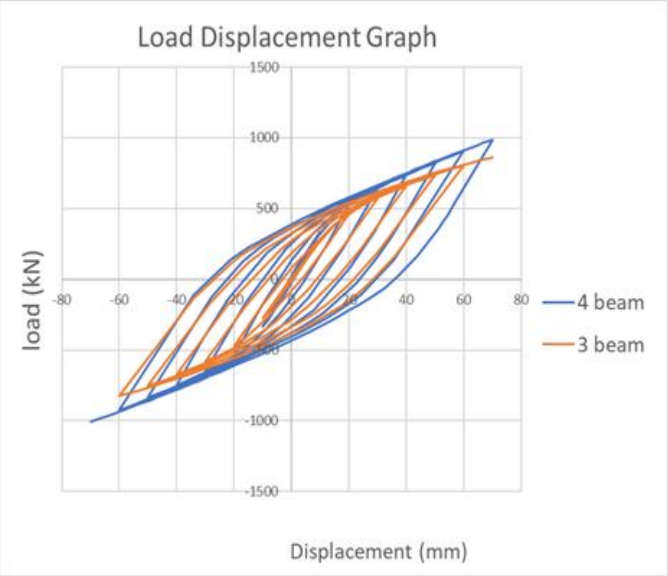



**Chart 4:** Load Carrying capacity Comparison of 3 beam – column system and 4 beam – column system

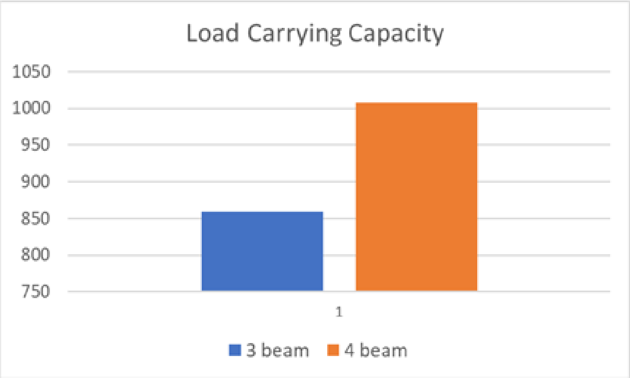
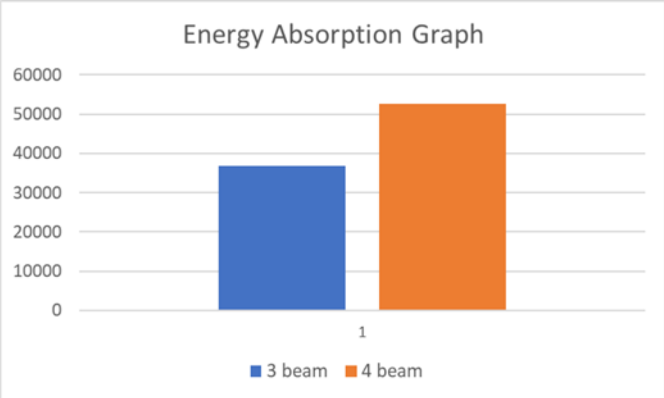


**Chart 5:** Load Carrying capacity Comparison of 3 beam – column system and 4 beam – column system




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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