

STRUCTURAL BEHAVIOR OF RETROFIT BEAM COLUMN JUNCTION USING ANSYS

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Abstract - The part of the column that is common to beam at their intersection in a building is known as the beam column joint. The fundamental purpose of beam column joint in reinforced concrete buildings is to transfer the load from connecting members effectively, while subjected to both gravity loads and seismic forces. The beam column joint is a portion that needs to resist lateral, longitudinal loads along with moment. They are the weakest link in RC moment resisting frame. Primarily due to the inadequate shear strength at the joints. In order to withstand these loads without causing damage, reinforced concrete frames must worksatisfactorily in extreme load conditions at beam column junction. Thus, proves to be a crucial aspect of structural design. The use of carbon fiber reinforced polymer (CFRP) materials in the retrofitting of beam column joints is notable, due to its high strength, stiffness, and corrosion resistance. Ansys Workbench is a powerful software tool for analyzing and designing beam-column joints in India. It enables detailed simulations and analysis, reducing the need for physical testing and streamlining the retrofitting process. With its advanced features and rapid design iterations, it enhances project efficiency and reduces costs. The present study focuses on the analysis and retrofitting of beam-column joints using carbon fiber reinforced polymer (CFRP) materials in Ansys Workbench, in the 2022 R2 Student and 2022 R1 Teaching versions. The study highlights the Total deformation and Maximum principal stress of retrofitted Beam Column joints compared to their original condition.

Key Words: Beam column joint, Ansys Workbench, Carbon Fibre Reinforced Polymer, Shear strength, corrosion.

1. INTRODUCTION

1.1 Opening Remark:

The retrofitting of existing concrete structures has become an increasingly important aspect of structural engineering, particularly when it comes to enhancing the strength and durability of beam column joints. Carbon fiber reinforced polymer (CFRP) jacketing is a popular retrofitting technique that can effectively increase the structural capacity of these joints. In this report, we will explore the use of

CFRP jacketing in retrofitting beam column joints and assess its effectiveness in improving the overall strength and stability of the structure. We will also utilize Ansys Workbench software to perform Finite Element Analysis (FEA) simulations and gain a deeper understanding of the structural behavior before and after retrofitting. Furthermore, this report will include a detailed cost analysis of the retrofitting process, taking into account the cost of materials, labor, and project timeline to provide a comprehensive understanding of the financial feasibility of this retrofitting technique.

1.2 Beam Column Joint:

The beam-column joint is one of the critical elements in reinforced concrete structures. It connects the vertical and horizontal members, thereby transferring the loads from the slab and beam to the columns. The behavior of the beam-column joint under various loads is of utmost importance for the safety and durability of the structure. The shape, size, and detailing of the beam-column joint have a significant influence on its performance. The integrity of the beam-column joint plays a vital role in the overall strength of the structure. Any failure or deformation in the joint can lead to the collapse of the structure. The reinforcement in the beam-column joint is critical for its performance. The steel reinforcement provides strength and ductility to the joint, enabling it to resist the forces induced by the loading conditions. The detailing of the reinforcement, including its spacing, arrangement, and development length, is critical for the proper functioning of the joint.

1.3 Retrofitting:

Retrofitting of structures has become increasingly important due to the aging of infrastructure, increased loads, and changes in design codes. Retrofitting is the process of strengthening or upgrading existing structures to improve their performance under current and future loading conditions. The retrofitting of structures involves adding new elements or strengthening existing ones to improve their load-carrying capacity, ductility, and resistance to earthquakes and other natural disasters. Retrofitting of joints involves increasing the size and strength of the joint to

improve its load-carrying capacity and ductility. The retrofitting of beam-column joints using FRP wraps involves wrapping the joint with layers of carbon or glass fiber sheets. The FRP wrap acts as a strengthening element increasing the load-carrying capacity and ductility of the joint.

1.4 Ansys Software:

Ansys Workbench is a powerful software tool widely used in the field of structural design and analysis. The software is particularly useful for retrofitting applications, allowing for the accurate simulation of different retrofitting techniques before they are implemented in the real world. Ansys Workbench offers a range of simulation capabilities, including finite element analysis (FEA), static and dynamic analysis, and other related simulations.

1.5 Beam Column Joint analysis before and after retrofitting:

This report aims to study the behaviour of the beam-column joint under different loading conditions and to analyze the joint's response before and after retrofitting using Ansys Workbench. The study will focus on the analysis of the joint's performance under seismic loads. The retrofitting of beam-column joints using different materials and techniques has been proven effective in improving the joint's behaviour and enhancing the overall structural performance of buildings.

The report will consist of a detailed literature review of previous studies conducted on beam-column joints' behaviour and retrofitting techniques. An overview of the analytical methods and modelling techniques used in the analysis of beam-column joints will also be presented. The report will then focus on the simulation of the beam-column joint in Ansys Workbench and the analysis of its response to seismic loads before and after retrofitting. The results obtained from the simulation will be used to evaluate the effectiveness of different retrofitting techniques.

2. METHODOLOGY

2.1 Material Specification:

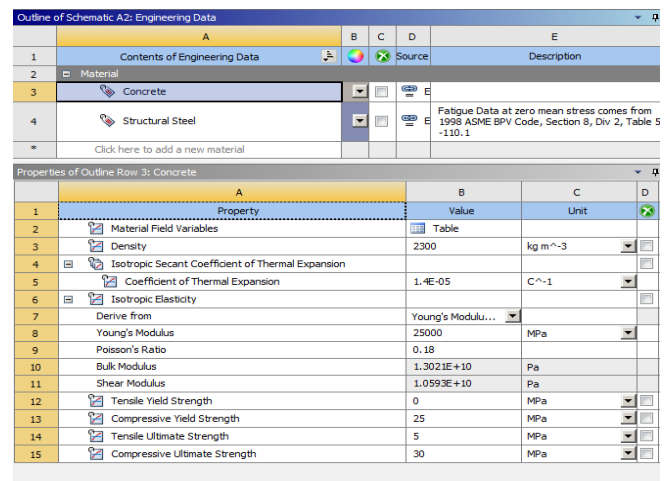
Concrete:

The grade of concrete used is M25, which has a strength of 25 N/mm² achieved after 28 days of curing. The proportion of cement, sand, and aggregate used is 1:1:2, which corresponds to approximately 8 bags of cement, 4.4 m³ of sand, and 8.8 m³ of aggregate.

The material properties of concrete used in this study are as follows:

- Thermal Conductivity: 1.44 W/mK
- Specific Heat: 1000 J/kgK

- Density: 2400 kg/m³
- Coefficient of Thermal Expansion: 1.2 x 10⁻⁵/°C
- Isotropic Elasticity: Derived from
- Young's Modulus: 30 GPa
- Poisson's Ratio: 0.2
- Bulk Modulus: 38 GPa
- Shear Modulus: 15 GPa
- Tensile Yield Strength: 3 MPa
- Compressive Yield Strength: 25 MPa
- Tensile Ultimate Strength: 4 MPa
- Compressive Ultimate Strength: 30 MPa



Property	Value	Unit
Density	2300	kg m ⁻³
Isotropic Secant Coefficient of Thermal Expansion		
Coefficient of Thermal Expansion	1.4E-05	C ⁻¹
Isotropic Elasticity		
Derive from	Young's Modulu...	
Young's Modulus	25000	MPa
Poisson's Ratio	0.18	
Bulk Modulus	1.3021E+10	Pa
Shear Modulus	1.0593E+10	Pa
Tensile Yield Strength	0	MPa
Compressive Yield Strength	25	MPa
Tensile Ultimate Strength	5	MPa
Compressive Ultimate Strength	30	MPa

Figure 1: Concrete Properties

Structural steel:

The structural steel used in the project is Fe500 TMT steel bars with yield strength of 500 N/mm² and an approximate elongation of 12%. This type of steel has high ductility and tensile strength, which increases the efficiency of the structure.

- Density: 7850 kg/m³
- Thermal Conductivity: 60.5 W/m-°C
- Specific Heat: 434 J/kg C
- Nonlinear Behaviour: False
- Assigned Bodies: 160
- Coefficient of Thermal Expansion: 1.2E-05C⁻¹
- Isotropic Elasticity: Derived from Young's Modulus, which is 2.1E+05 MPa

- Poisson's Ratio: 0.3
- Bulk Modulus: 1.75E+11 Pa
- Shear Modulus: 8.0769E+10 Pa
- Strain-Life Parameters:
- Tensile Yield Strength: 500 MPa
- Compressive Yield Strength: 250 MPa
- Tensile Ultimate Strength: 560 MPa
- Compressive Ultimate Strength: 0 MPa

Parameters (All dimensions in mm)	Model1 Without Headed Bars	Model 2 With Headed Bars
1. Sectional Size of Beam	180 X 150	180 X 150
2. Sectional Size of Column	200 X 150	200 X 150
3. Length of Column (mm)	780	780
4. Length of Beam	600	600
5. Reinforcement Detailing of Longitudinal Bars of Column	4 - #12mm	4 - #12mm
6. Lateral Ties	#6mm @10mmc/c	#6mm @100mmc/c
7. Reinforcement Detailing of Longitudinal Bars of Beam	4 - #12mm	4 - #12mm
8. Stirrups	#6mm @75mm c/c	#6mm @75mmc/c

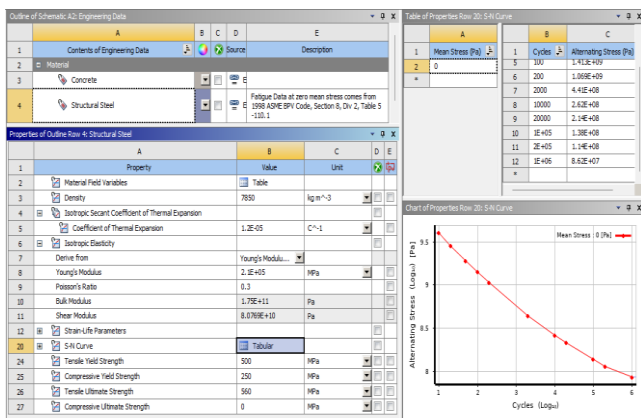


Figure 2: Structural Steel Properties

- Density: 1800 kg/m³
- Orthotropic Elasticity:
- Young's Modulus in X direction: 2.3E+11 Pa
- Young's Modulus in Y direction: 2.3E+10 Pa
- Young's Modulus in Z direction: 2.3E+10 Pa
- Poisson's Ratio XY: 0.2
- Poisson's Ratio YZ: 0.4
- Poisson's Ratio XZ: 0.2
- Shear Modulus XY: 9E+09 Pa
- Shear Modulus YZ: 8.2143E+09 Pa
- Shear Modulus XZ: 9E+09 Pa

Carbon Fiber Polymer:

Fiber reinforced polymers (FRPs) are a new type of lightweight, high-strength material that are non-corrosive. They are made by combining a thermosetting plastic, such as epoxy or polyester, with a fiber, such as carbon or glass. The use of FRP materials is particularly effective in improving the stiffness and strength of structures. Carbon fibers, which contain 80-95% carbon and can be in either staple or filament form, are a popular choice due to their low density and high strength and stiffness properties.

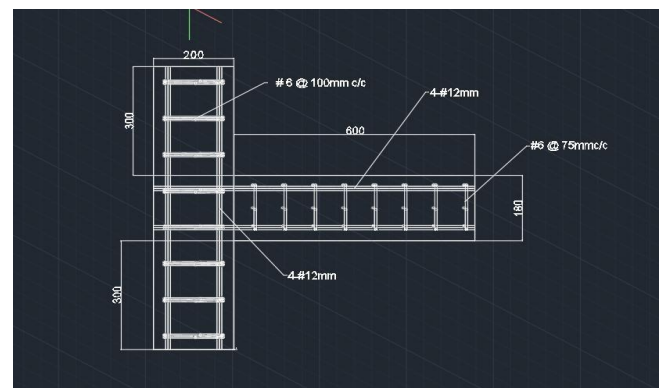


Figure 5: 3D Model in AutoCAD showing dimensions for Model 1 and Model 2

Creating Geometry in Ansys Space claim:

Step 1: Choose a static structural analysis system and select the desired geometry for analysis.

Step 2: Open the Design Modeler window and select the unit of measurement as millimeters. Then, select a specific plane and sketch the external dimensions of the column in 3D. Name this shape as 'Column 200mm x 150mm'.

Step 3: Draw the main steel or longitudinal bars in the column by extruding circles with a diameter of 12mm. Move this shape to a new component named 'Circle'. Provide a 40mm cover in red colour.

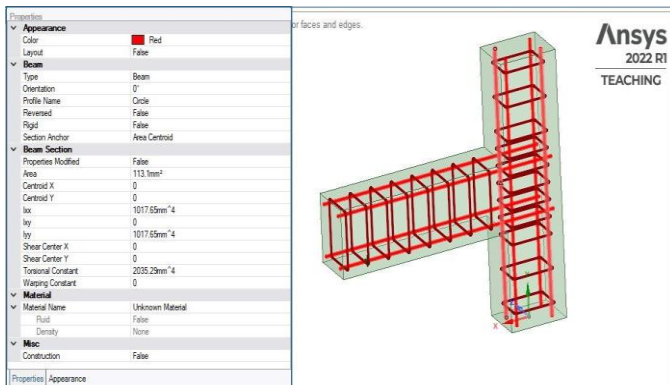


Figure 6: Properties and name used for Main steel bars

Step 4: Next, sketch the lateral ties for the column with the name 'Circle2' in a maroon colour and with a diameter of 6mm. Create a pattern for the ties to meet the required design specifications.

Step 5: Similarly, create the geometry for the beam and its reinforcement with a 25mm cover. Create two models: one with a head and one without a head on the development bar.

1. To create the retrofitted model, extrude the external dimensions and add a wrapping layer of 1.25mm to the geometry

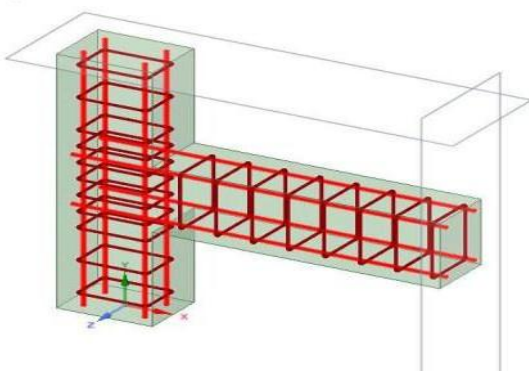


Figure 8: Geometry of Model1 to be retrofitted

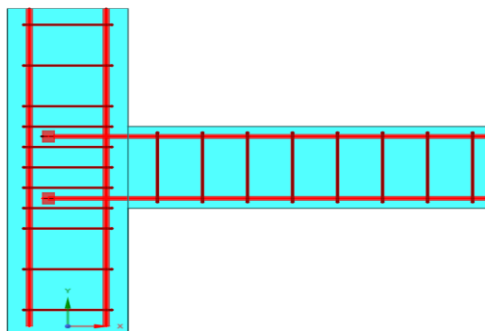


Figure 9: Geometry of Model2 to be retrofitted

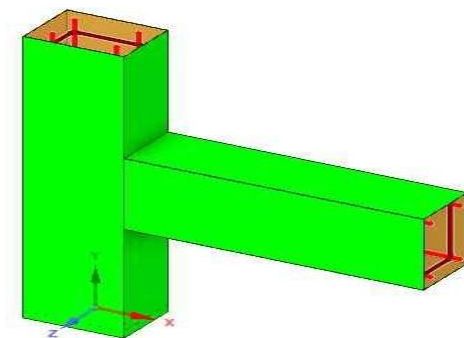
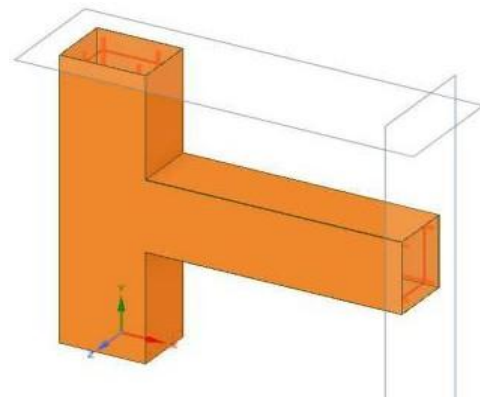
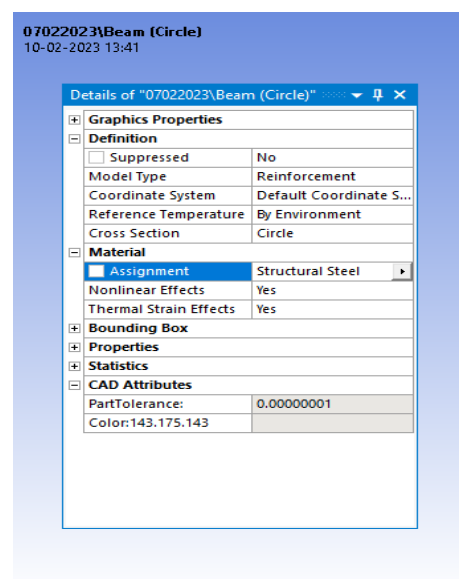


Figure 10: CFRP Wrapping on Model 1 and Model 2

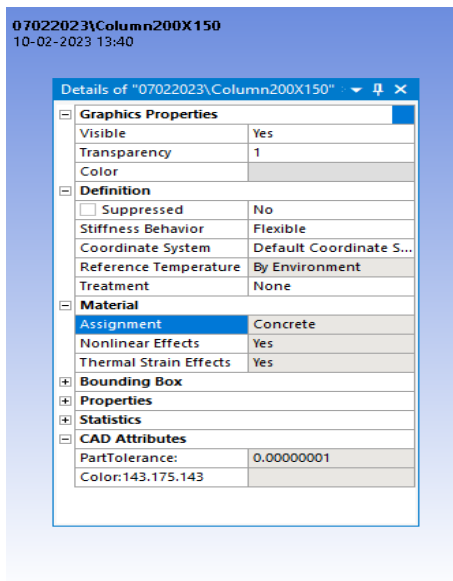
Modelling and Analysis:

Step for RCC Structure:

Step 1: Assigning Material Properties: Set the appropriate units and engineering data, including selecting and specifying the materials for the concrete and structural steel.



(a)

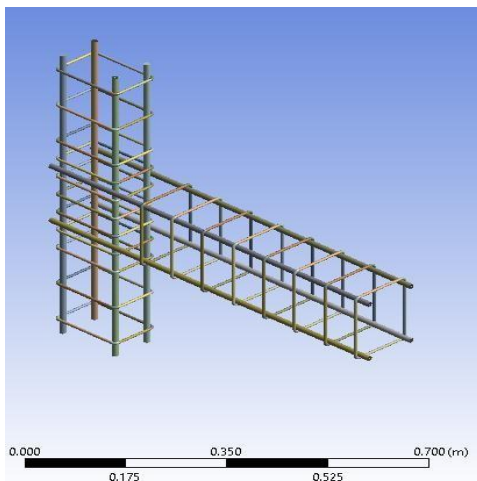


(b)

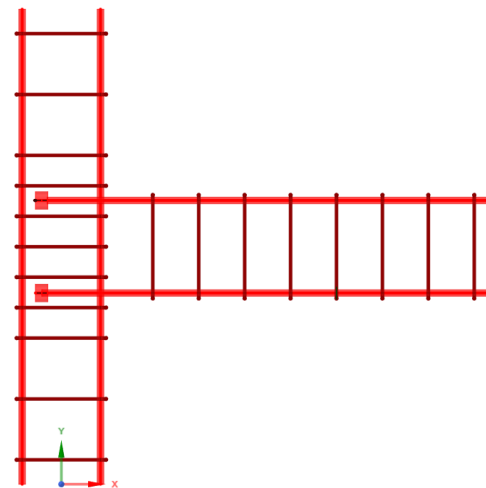
Figure 12: Properties of Beam and Column in Ansys Workbench

Step 2: Importing Geometry: Import the geometry from SpaceClaim Design Modeller and open the model in ANSYS Workbench.

Step 3: Reinforcement Assignment: Choose all the line elements, and reassign them to structural steel. Additionally, set the model type to reinforcement, as the beams serve as reinforcement components within the concrete structure.



(a)



(b)

Figure 14: Reinforcement Property Assigned

Step 4: Concrete Assignment: Click on the body of the structure, change the assignment to concrete, and add the corresponding commands to define the material properties for the concrete. This will ensure that the simulation accurately models the behaviour of the reinforced concrete structure.

Step 5: Generating Mesh: Create a linear mesh with an element size of 40mm, 5123 nodes, and 1200 elements. This will enable the ANSYS Workbench software to analyze the reinforced concrete structure efficiently and accurately.

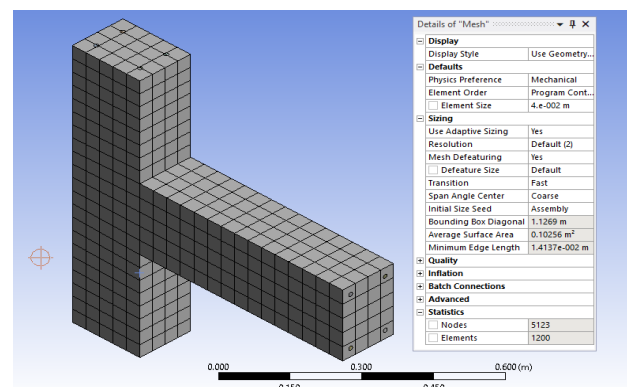


Figure 16: Properties of Mesh for Reinforced Concrete Beam Column Joint.

Step 6: Assigning Fixity: Configure the analysis settings by selecting the appropriate parameters such as displacement, force, and fixed support for specific faces or edges. Turn on the large displacements option to accurately model the behaviour of the structure under load. Set the boundary conditions as fixed support at the bottom and hinged support at the top face.

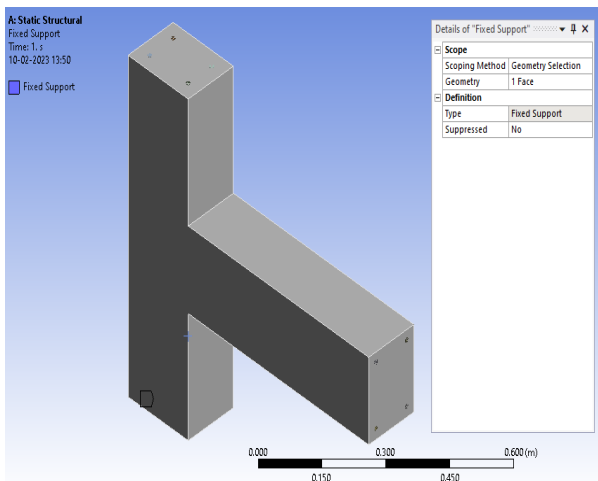


Figure 17: Details of Fixed Support at Bottom Face

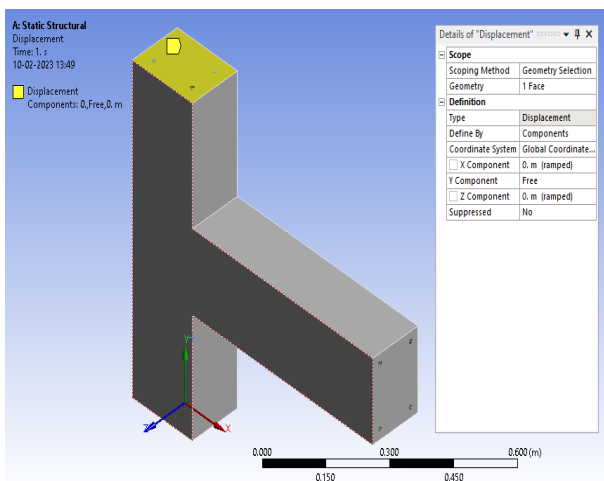


Figure 18: Details of Hinge support at Top Face

Step 7: Applying UDL: Apply a force of 80kN/m in the vertical direction (Y plane) as a uniform distributed load (UDL). This will simulate the structure's behaviour under load.

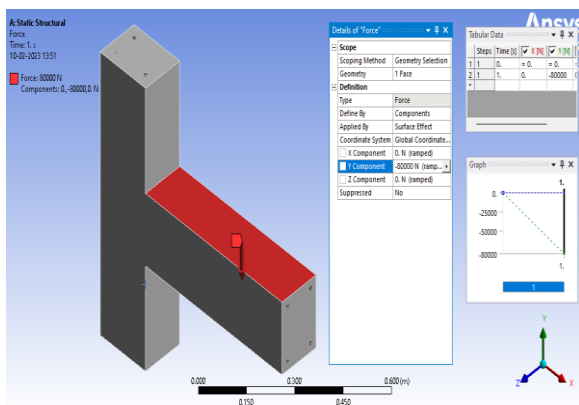


Figure 19: Loading Conditions

Step 8: Simulation: Click the solve button to initiate the simulation. analyze the total deformation, deformation of the reinforcement components, maximum principal stress, and maximum principal stress on the reinforcement components to evaluate the structural performance under load.

Step for Retrofitted RCC Structure:

Step 1: Assign the appropriate units and engineering data, including selecting and specifying the materials for the carbon fibre used in the retrofitting process.

Step 2: Import the geometry from SpaceClaim Design Modeller and open the model with the CFRP wrapping of 1.25mm applied to the structure.

Step 3: Define the material properties for the carbon fiber and the existing structure, ensuring that the simulation accurately reflects the behaviour of the retrofitted structure.

Step 4: Create a tetrahedral mesh with an element size of 20mm, which will enable ANSYS Workbench to analyze the retrofitted structure efficiently and accurately.

Step 5: Configure the analysis settings by selecting the appropriate parameters such as displacement, force, and fixed support for specific faces or edges. Turn on the large displacements option if necessary to accurately model the behaviour of the structure under load.

Step 6: Click the solve button to initiate the simulation. Analyze the total deformation, deformation of the reinforcement components, maximum principal stress, and maximum principal stress on the reinforcement components to evaluate the structural performance under load.

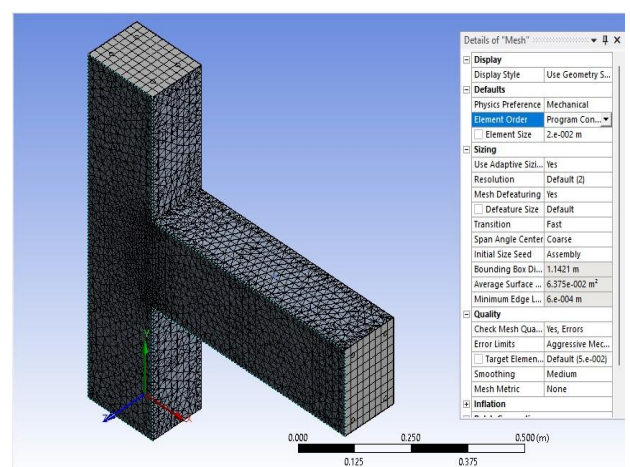


Figure 20: Details of Mesh

Manual Calculation by IS Method:

As maximum allowable deflection δ_{max} is greater than obtained deflection δ , hence the member is safe against deflection.

Manual Calculation by EN Method:

Based on this method the deflection $\delta_{QP} = 1.68$ mm

is less than the maximum allowable deflection

$$\delta_u = 4.00 \text{ cm i.e. } 40\text{mm.}$$

Therefore, the check is satisfied.

RESULTS AND DISCUSSION

Opening Remark:

The use of carbon fiber-reinforced polymer (CFRP) composites in construction has gained considerable attention in recent years due to their excellent mechanical properties and durability. One of the areas where FRP composites have shown promising results is in beam column joints, which are critical components in reinforced concrete structures. In this study, we compare the performance of RCC beam column joints with that of CFRP beam column joints using Ansys. The aim of this comparison is to evaluate the effectiveness of using CFRP (Carbon Fiber Reinforced Polymer) composites as a strengthening technique for RCC (Reinforced Cement Concrete) beam-column joints. This study utilizes Ansys Workbench software to analyse and compare the structural behaviour of RCC and CFRP-strengthened beam-column joints.

Results:

- 1) The results of this study show that CFRP wrapping can significantly improve the strength and performance of beam-column joints.
- 2) The study found that CFRP wrapping can reduce deformation by up to 26.23% and increase stress by up to 6.41 times for Model 1 (without headed bar), and can reduce deformation by up to 27.05% and increase stress by up to 6.30 times for Model 2 (with headed bar).
- 3) These results suggest that CFRP wrapping is a viable and effective method for strengthening beam-column joints.

Analysis of RCC Beam Column Joint:

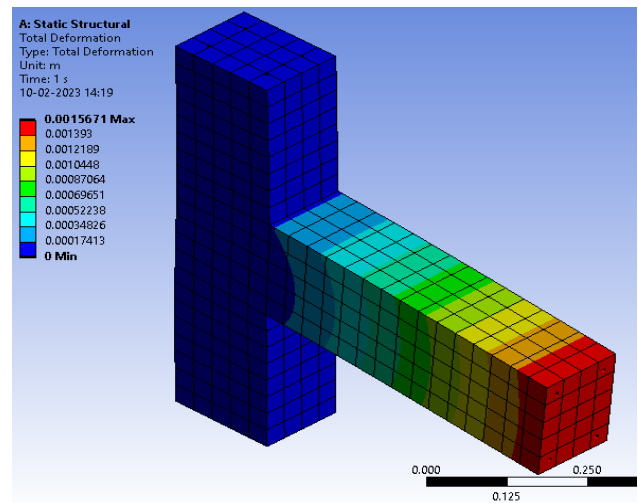


Figure 21: Total Deformation for Reinforcement in Reinforced Concrete Model 1

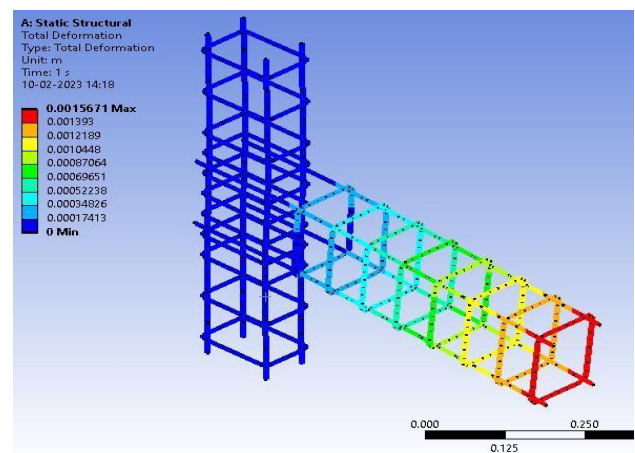


Figure 22 : Total Deformation for Reinforcement in Reinforced Concrete Model 1

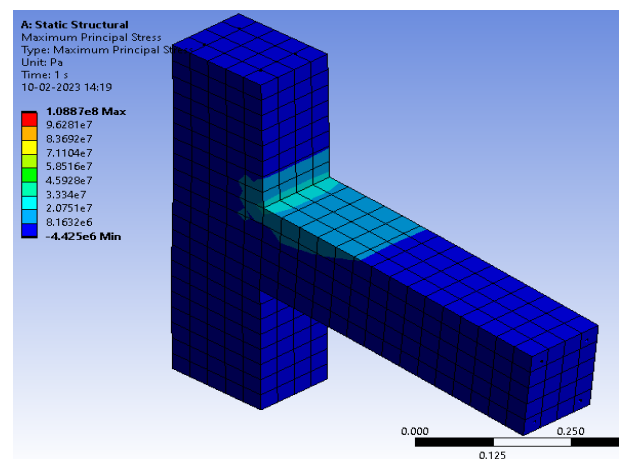


Figure 23: Maximum Principal Stress for Reinforced Concrete Model 1

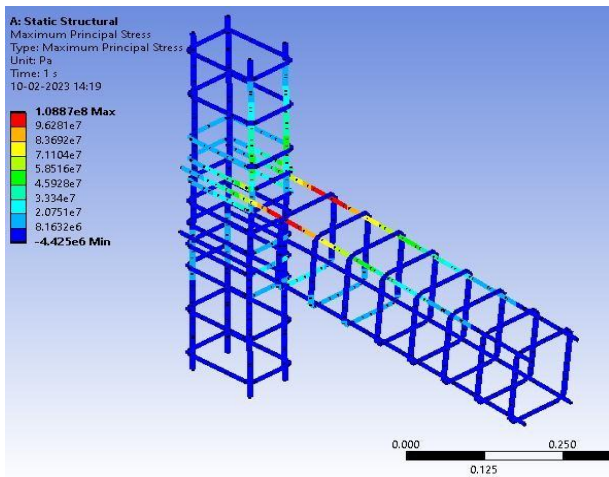


Figure 24: Maximum Principal Stress for Reinforcement in Reinforced Concrete Model 1

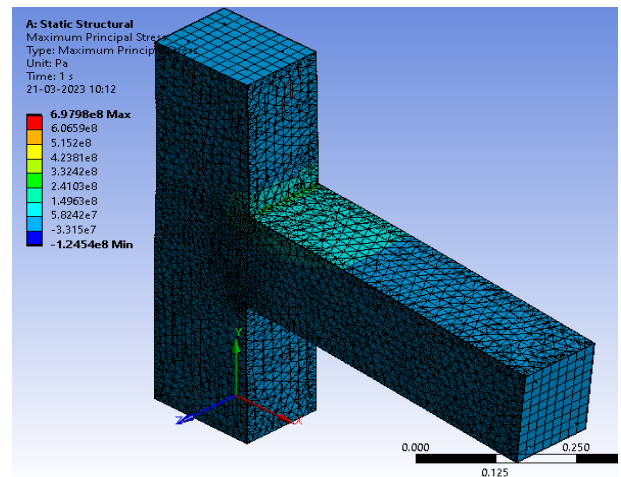


Figure 27: Maximum Principal Stress for Retrofitted Model 1

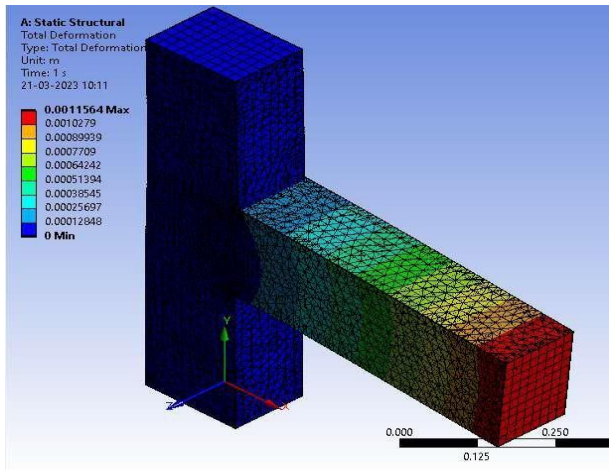


Figure 25: Total Deformation for Retrofitted Model 1

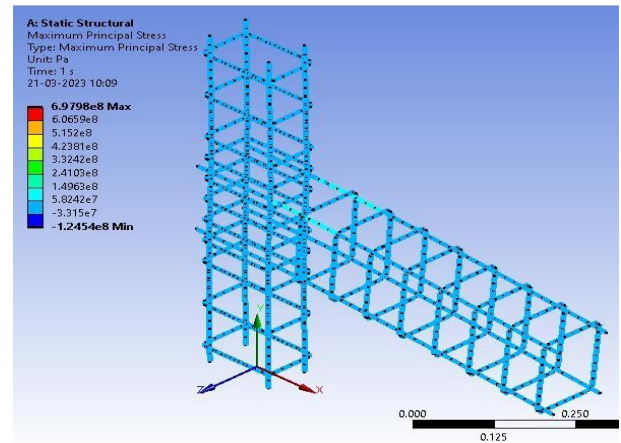


Figure 28: Maximum Principal Stress for Reinforcement in Retrofitted Model

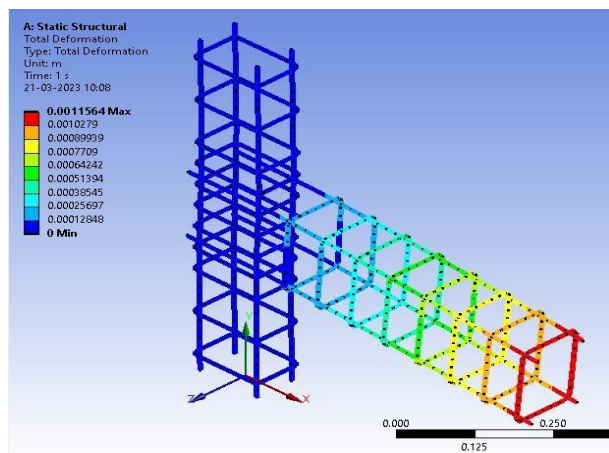


Figure 26: Total Deformation for Reinforcement in Retrofitted Model 1

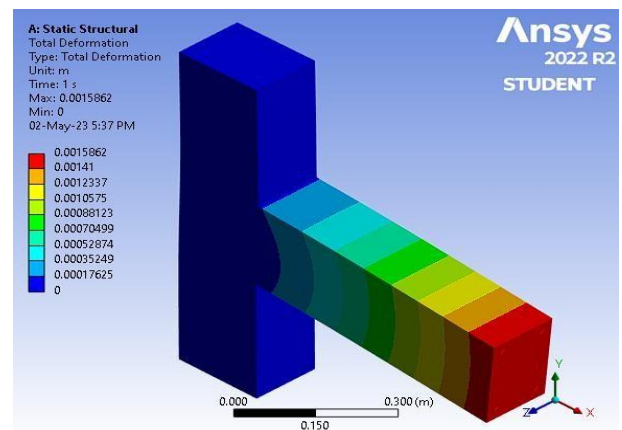


Figure 29: Total Deformation in Reinforced Concrete Model 2

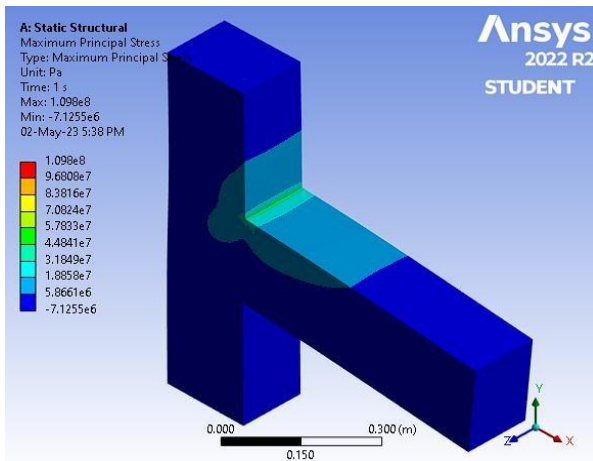


Figure 30: Maximum Principal Stress in Reinforced Concrete Model

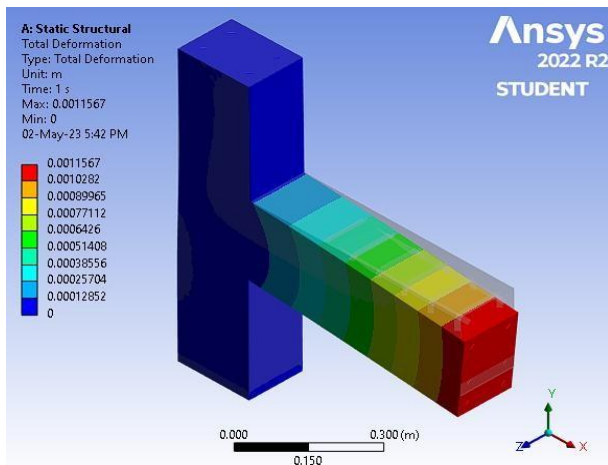


Figure 31: Total Deformation in Retrofitted Model 2

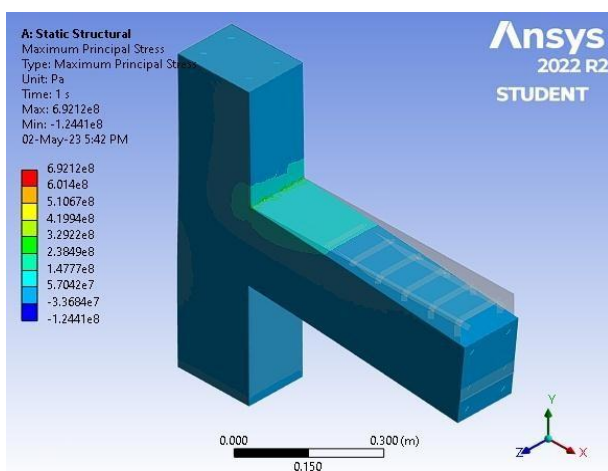


Figure 32: Maximum Principal Stress in Retrofitted Model 2

Figures 21-24 represent the analysis results of the concrete model without headed bars. Figure 21 shows the deformation of the concrete body, and Figure 22 illustrates the deformation of the reinforcement bars. Figure 23 presents the distribution of maximum principal stress in the concrete body, while Figure 24 displays the maximum principal stress in the reinforcement bars.

Figures 25-28 showcase the analysis results of the CFRP model without headed bars. Figure 25 displays the deformation of the concrete body, and Figure 26 illustrates the deformation of the reinforcement bars. Figure 27 presents the distribution of maximum principal stress in the concrete body, while Figure 28 shows the maximum principal stress in the reinforcement bars.

Figures 29-30 depict the analysis results of the concrete model with headed bars. Figure 29 shows the deformation of the concrete body, and Figure 30 illustrates the distribution of maximum principal stress in the concrete body.

Figures 31-32 represent the analysis results of the CFRP model with headed bars. Figure 31 displays the deformation of the concrete body, and Figure 32 illustrates the distribution of maximum principal stress in the concrete body.

Cost Analysis:

It provides the results obtained for Model 1 (Without Headed Bars) and Model 2 (With Headed Bars) with and without CFRP wrapping. The table includes the Total deformation in mm, Maximum principal stress in MPa, % of Deformation regained, and the number of times Stress increased for each model. These results illustrate the impact of CFRP wrapping on reducing deformation and increase in the maximum principal stress in both Model 1 and Model 2 of the beam-column joints.

The cost breakdown for the project is as follows: 0.0396 cubic meters of concrete is required at a rate of Rs. 11000 per cubic meter, resulting in a total cost of Rs. 435.6. For steel, 5.1395 kilograms are needed at a rate of Rs. 89000 per metric ton, amounting to a total cost of Rs. 457.4155. Additionally, 0.942 square meters of formwork is required at a rate of Rs. 1300 per square meter, totaling Rs. 1224.6. Demolition work will take 1 day at a rate of Rs. 2000 per day, with a cost of Rs. 2000. For labor, 5 days are needed at a rate of Rs. 650 per day, resulting in a cost of Rs. 3250. Therefore, the overall total cost comes to Rs. 7367.616.

The total cost breakdown for the project is as follows: 3 square meters of FRCP (Fiber Reinforced Composite Panels) at a rate of Rs. 1200 per square meter, amounting to a total cost of Rs. 3600. Additionally, 0.5 kg of adhesive is needed at a rate of Rs. 1000 per kg, totaling Rs. 500. The cost of

hardener is not specified. For labor, 615 days of semi-skilled labor are required at a rate of Rs. 2 per day, resulting in a cost of Rs. 1230. Furthermore, 650 days of skilled labor are needed at a rate of Rs. 1 per day, with a total cost of Rs. 650. Thus, the overall total cost comes to Rs. 5980.

CONCLUSION

Through a comprehensive analysis using Ansys Workbench software and referencing previous research, the objectives were successfully achieved. Model 1 experienced 6.41 times increase in Maximum Principal Stress and a 26% reduction in total deformation, while model 2 showed 6.30 times increase in Maximum Principal Stress and a 27.05% reduction in total deformation. Comparing the performance of both reinforcement patterns before and after retrofitting, the Maximum Principal Stress and Deformation were nearly equal. Additionally, the average difference between analytical and software-based results was 5.4%. The cost of retrofitting a member using CFRP wrapping was Rs. 6000, while the cost for reconstructing a member was Rs. 7287.75.

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