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Rehabilitation of RC Beam–column Junction Having Lack of Detailing Using CFRP Sheets

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***Abstract*— This study presents the rehabilitation of reinforced concrete (RC) beam–column junctions which lack detailed reinforcement, using Carbon Fiber Reinforced Polymer (CFRP) sheets. The deterioration and inadequate detailing often lead to structural failures, especially in seismic zones. Through the application of CFRP sheets, the structural integrity and load-bearing capacity of these junctions can be enhanced significantly. Experimental results demonstrate the efficacy of this rehabilitation technique in extending the service life and improving the safety of the existing RC structures.**

***Keywords*— Rehabilitation, RC Beam-Column Junction, CFRP Sheets, Structural Integrity, Load-bearing Capacity.**

I.INTRODUCTION

The integrity and safety of reinforced concrete (RC) structures are paramount in engineering, especially in seismic zones where beam-column junctions play a critical role in overall structural behavior. The rehabilitation of these junctions, particularly those with inadequate detailing, is crucial for enhancing their seismic resilience and longevity. This study explores the rehabilitation of RC beam-column junctions using Carbon Fiber Reinforced Polymer (CFRP) sheets, a method gaining popularity due to its effectiveness in improving strength and ductility while being minimally invasive.

The lack of proper detailing at these junctions often leads to severe structural vulnerabilities during seismic events, characterized by inadequate reinforcement anchorage and poor joint performance. The primary focus of this research is to develop a reliable rehabilitation approach using CFRP sheets to address these deficiencies, thus ensuring the junctions meet current engineering standards and performance expectations.

This paper presents a comprehensive analysis of the structural behavior of beam-column junctions both pre and post-rehabilitation. The methodology involves detailed finite element modeling followed by experimental validation to assess the efficacy of CFRP sheets in restoring and enhancing the structural capacity of deficient junctions.

The significance of this study lies in its potential to contribute to safer, more reliable RC structures in seismic areas, offering practical solutions for engineers and professionals in construction and maintenance of critical infrastructure.

II.LTERATURE REVIEW

The literature on the rehabilitation of reinforced concrete (RC) beam-column junctions using Carbon Fiber Reinforced Polymer (CFRP) sheets is extensive and highlights various methodologies and outcomes that underscore the complexity and significance of effective rehabilitation strategies. This review examines key studies that have contributed to the current understanding of CFRP application in structural engineering, particularly focusing on seismic retrofitting and enhancement of structural deficiencies.

A. Efficacy of CFRP in Structural Rehabilitation

Karayannis et al. (2008) investigated the behavior of critical external beam–column junctions reinforced with CFRP jacketing combined with epoxy resin injection. The study demonstrated that CFRP sheets significantly enhance the load-carrying capacity and energy absorption of the connections, suggesting a promising approach for seismic retrofitting. Similarly, Mukherjee et al. (2004) reported enhanced strength and ductility in beam-column junctions, irrespective of the original reinforcement detailing, when retrofitted with CFRP under cyclic loading, highlighting the material's versatility and effectiveness.

B. Comparative Analyses of Strengthening Techniques

Ghobarah (2001) focused on different rehabilitation schemes using GFRP sheets and emphasized the shift in failure modes from brittle to more ductile, which is crucial for seismic resilience. Antonopoulos et al. (2003) further confirmed that FRP materials, including CFRP, significantly contribute to the shear capacity of junctions, which is critical in preventing catastrophic failures during earthquakes.

C. Innovations and Improvements in Application Methods

Recent advancements in application techniques were explored by Zamani Beydokhti et al. (2016), who studied the behavior of shear-deficient beam-column junctions retrofitted by CFRP. Their findings suggest that the method of CFRP application can greatly influence the effectiveness of the rehabilitation, with techniques such as grooving and NSM (Near Surface Mounted) showing potential for enhanced performance and longevity of the retrofit.

D. Challenges and Considerations in CFRP Application

Despite the positive outcomes, the literature also discusses challenges such as the proper alignment and anchorage of CFRP sheets, the effects of environmental factors on adhesive properties, and the long-term durability of the retrofit. These factors are critical in the design and implementation of CFRP rehabilitation strategies to ensure they are both effective and sustainable.

CONCLUSION

The review of existing literature indicates a strong consensus on the effectiveness of CFRP sheets in enhancing the structural integrity of beam-column junctions. However, it also highlights the need for continued research into optimized application techniques, long-term performance, and cost-effectiveness of CFRP retrofitting solutions. This study contributes to this ongoing research effort by proposing a novel approach to the rehabilitation of RC junctions using CFRP, aiming to address some of the identified gaps and challenges.

III. ANALYSIS AND DESIGN OF R.C. BEAM-COLUMN JUNCTION USING STAAD PRO

STAAD Pro is renowned for its capabilities in structural analysis and design, particularly in modeling the integrity and sustainability of complex structures like RC beam-column junctions. This chapter details the use of STAAD Pro to analyze and design an RC beam-column junction, emphasizing structural integrity under various load conditions.

Modeling and Analysis Method

This analysis starts with creating a detailed geometric model of the beam-column junction. Essential parameters, such as material properties, boundary conditions, and loading scenarios, are defined based on the junction's operational environment requirements.

1. Geometry and Material Specification: The model integrates a beam and column system. The dimensions and material properties reflect typical construction practices and the requirements of relevant structural design codes.

TABLE 1: MATERIAL PROPERTIES AND DIMENSIONS

Property	Specification
Concrete Grade	M25
Steel Grade	Fe500
Beam Dimensions	300 mm x 500 mm
Column Dimensions	400 mm x 400 mm
Cover	40 mm

2. Load Application and Boundary Conditions: The structure undergoes typical loading scenarios anticipated during its service life, including vertical loads and horizontal seismic forces. You.

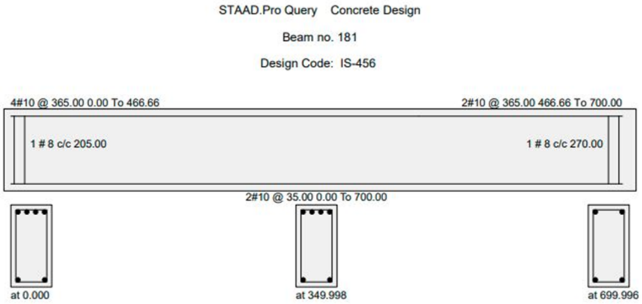

Figure 1. Reinforcement design of beam

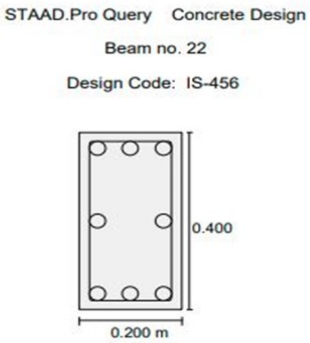

Figure 2. Reinforcement design of column

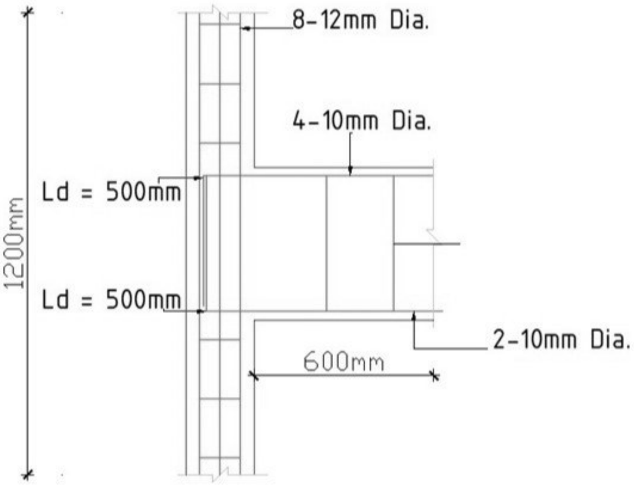

Figure 3. Reinforcement layout of beam-column junction

IV. FE MODELING OF R.C. BEAM-COLUMN JUNCTION USING ABAQUS

Abaqus is widely recognized for its advanced finite element analysis capabilities, essential for examining the structural behavior of reinforced concrete (RC) beam-column junctions under various load conditions. This chapter describes the methodology and key findings from using Abaqus to perform finite element modeling and analysis of an RC beam-column junction, emphasizing the understanding of mechanical responses and potential failure mechanisms.

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Model Development and Setup

The development of the finite element model is meticulously detailed here, including the geometric specifications, material properties, and the setup of boundary conditions.

1. Geometry and Meshing: The model accurately represents an integrated beam and column system. The meshing strategy involves using finer meshes at regions expected to experience higher stress concentrations to capture accurate stress gradients.

Table 2: Mesh Specifications And Material Properties

Feature	Specification
Mesh Type	Fine mesh near connections, coarser elsewhere
Element Type	Solid elements suitable for concrete and steel
Concrete Model	Nonlinear, including damage plasticity
Steel Model	Elastic-plastic with hardening

2. Boundary Conditions and Loading: The model incorporates realistic constraints that replicate support conditions, and loads are applied to mimic real-world forces, including gravitational, live, and lateral seismic loads.

Analysis Methodology

1. Loading Scenarios: The static analysis examines serviceability under typical loads, whereas dynamic analysis assesses the response to seismic events, providing insights into the junction's resilience.
2. Computational Steps: Simulations involve sequential load applications to progressively study the junction's behavior and identify critical loading stages.

Scope of Work

1. The principal aim of the finite element analysis (FEA) of the beam-column junction presented in this chapter was to investigate its static behavior under service loads. This analysis provides a deep understanding of the structural responses of the junction, highlighting areas that may require further research and more detailed examination.
2. In this study, the beam-column junction was subjected to a variety of load scenarios. Each set of conditions was meticulously designed to replicate realistic service loads that the junction might encounter during its operational life. The responses of the junction were analyzed under these varying conditions to understand its behavior in different situations and under different boundary conditions.

Table 3: Scope Of Work For Fem

Grade	Strengthening scheme	Designations	No	Total Nos
M-25	DUCTILE BEAM-COLUMN JUNCTION	DBCJ -11	1	2
	NON-DUCTILE BEAM-COLUMN JUNCTION	NDBCJ-12	1	

Analysis Results

This section presents the results from the finite element simulations, focusing on stress distribution and deformation outcomes.

1. Specimen 1 (DBCJ-11)

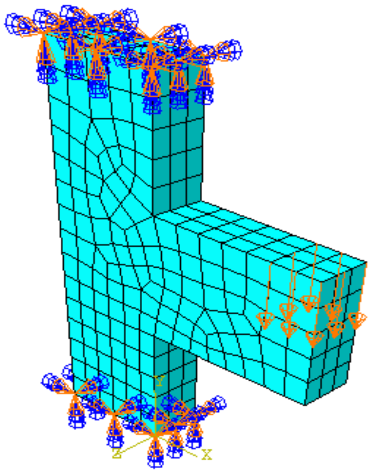

Figure 4: Meshing, Loading And Support Condition

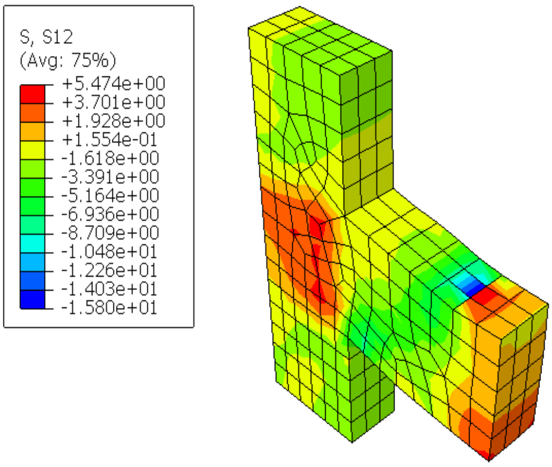

Figure 5: Shear Stress

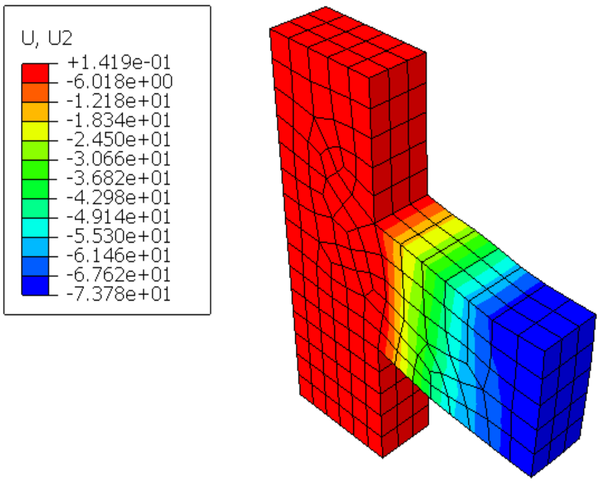

Figure 6: Discplacement Contour

2. Specimen 2 (NDBCJ-12)

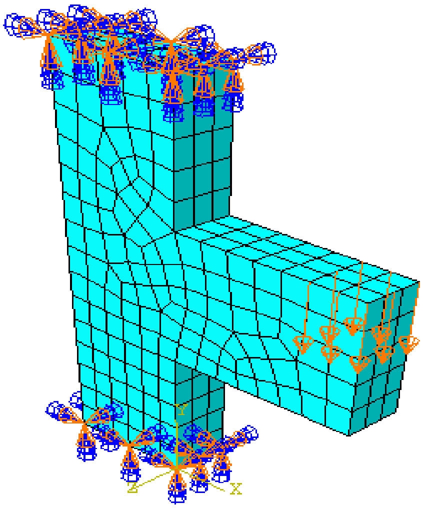

Figure 7: Meshing, Loading And Support Condition

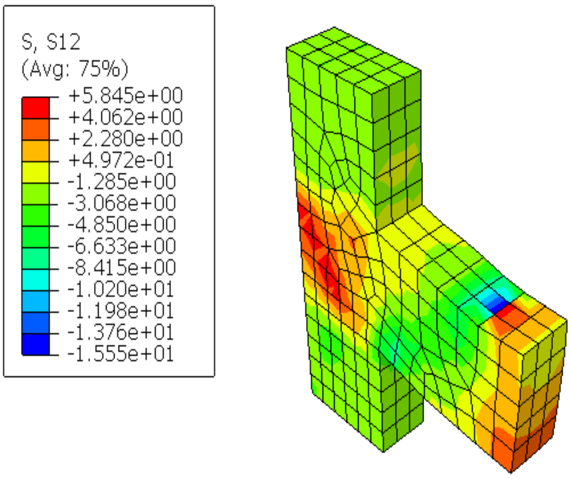

Figure 8: Shear Stress

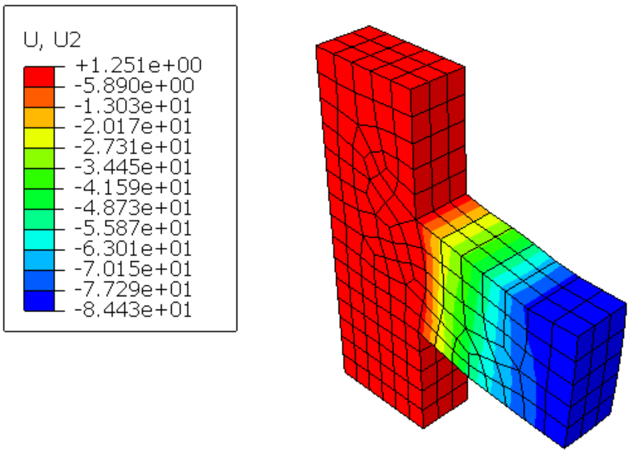

Figure 9: Discplacement Contour

V. RESULTS AND DISCUSSION

This chapter provides an in-depth analysis of the results from the finite element modeling of the RC beam-column junction, emphasizing the impact of rehabilitation using CFRP sheets. Detailed shear stress figures have guided the strategic application of CFRP sheets, aiming to improve the load-bearing capacity of both ductile and non-ductile junctions.

Interpretation of Shear Stress Distribution

The finite element model (FEM) produced a color-coded map that detailed the shear stress distribution within the beam-column junction. This gradient of stress levels, from low (blue) to high (red), showed the highest stress concentrations in the core of the junction. The areas highlighted in red were identified as susceptible to shear failure, as shown in figure 6 for the ductile junction and figure 9 for the non-ductile junction.

Rehabilitation Strategy Using CFRP Sheets

Using the detailed stress profiles from the FEM analysis, CFRP sheets were applied to the identified high-stress regions. This precise intervention aimed to reinforce the junction's shear capacity and foster a more equitable load distribution throughout the structure.

Load-Bearing Capacity Enhancement

The application of CFRP sheets exhibited quantifiable improvements in the load-bearing capacity, as demonstrated by the following graphs for ductile and non-ductile beam-column junctions:

1. Ductile Beam-Column Junction: The graph for the ductile junction shows that the ultimate load capacity increased significantly after applying CFRP sheets (orange line) compared to the pre-rehabilitation scenario (blue line).

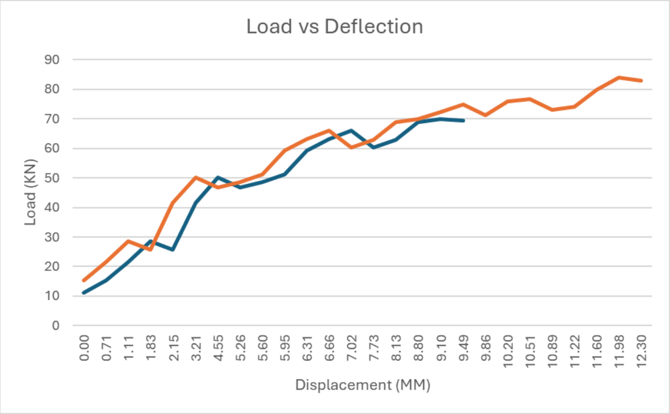

Figure 10: load vs. Deflection for ductile beam-column junction

2. Non-Ductile Beam-Column Junction: Similarly, the non-ductile junction graph displays an increase in load capacity and deflection with CFRP sheet application, indicating an enhancement in structural resilience.

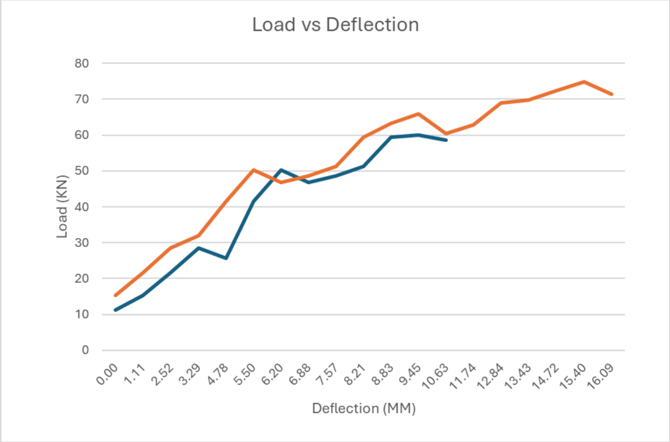

Figure 11: load vs. Deflection for non-ductile beam-column junction

Discussion on Structural Performance

The CFRP sheets' rehabilitation success is discussed with a focus on:

1. Ductile Junctions: The improvement in ductile junctions' performance with CFRP sheets not only increases the ultimate load capacity but also the deformation capability, critical for structural resilience.
2. Non-Ductile Junctions: The significant gains in load-bearing capacity for non-ductile junctions demonstrate the CFRP sheets' effectiveness in bringing their performance closer to ductile behavior standards.

VI. CONCLUSION

This study set out to address the structural vulnerabilities of reinforced concrete (RC) beam-column junctions using Carbon Fiber Reinforced Polymer (CFRP) sheets, guided by finite element analysis (FEA). The research identified critical stress points susceptible to failure under service loads, and it applied CFRP sheets to improve both the load-bearing capacity and ductility of the junctions.

Achievements of the Study

The application of CFRP sheets, as informed by the detailed shear stress distribution analysis, demonstrated a significant improvement in the structural performance of the beam-column junctions. This was evidenced by:

- An increase in load-bearing capacity for both ductile and non-ductile junctions.
- A redistribution of stress within the junctions, leading to enhanced shear resistance.
- Improved deformation behavior, increasing the ductility and energy absorption of the junctions during loading, as evident in figures 10 and 11 for the ductile and non-ductile junctions, respectively.

Implications for Structural Engineering

The results of this study hold significant implications for the field of structural engineering, particularly in the design and rehabilitation of RC structures:

- Demonstrating the efficacy of CFRP sheets offers a viable solution for enhancing the seismic resilience of existing structures.
- The methodologies employed in this study provide a framework for employing FEA as a tool for targeted structural enhancements.
- The study underscores the importance of proactive structural health monitoring and rehabilitation to extend the service life of critical infrastructure.

Recommendations for Future Work

Based on the study's outcomes, the following recommendations are proposed for future research:

- Investigate the long-term performance of CFRP-rehabilitated junctions under variable environmental conditions.
- Conduct large-scale experimental validations to corroborate the FEA results and assess the practical implementation of CFRP sheets in real-world scenarios.
- Explore the cost-benefit analysis of CFRP rehabilitation to establish economic viability alongside technical efficiency.

Concluding Remarks

The study concluded that CFRP sheets are a formidable option for the rehabilitation of RC beam-column junctions. By leveraging FEA to identify weak points and applying targeted CFRP reinforcements, the research showcased an effective method to significantly bolster the structural integrity of RC junctions. These findings contribute valuable knowledge to the ongoing efforts in the structural engineering field to enhance the safety and longevity of infrastructure in the face of increasing service demands and seismic challenges.

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