

## **STRUCTURAL PERFORMANCE OF REINFORCED CONCRETE BEAM-COLUMN JOINT RETROFITTED WITH CARBON FIBER REINFORCED POLYMER**

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### **ABSTRACT**

This study investigates the seismic retrofitting of damaged reinforced concrete beam-column joint using Carbon Fiber Reinforced Polymer (CFRP) sheets. A joint was cast with a concrete mix containing 15 mm long 0.25% Galvanized Iron (GI) fibers by volume to improve tensile strength and crack resistance. The joint was damaged under simulated seismic activity and later retrofitted with 200 gsm unidirectional CFRP sheets at the joint region to assess the effectiveness of CFRP retrofitting under reversed cyclic loading conditions. The specimen was tested up to a maximum drift ratio of 8%, evaluating load capacity, ductility, energy dissipation, and crack propagation. The retrofitted joint showed significant strength and stiffness recovery compared to their pre-retrofitted damaged state. The CFRP wrapping enhanced confinement, reduced crack widths, and delayed strength degradation. GI fibers improved damage tolerance, while the CFRP sheets restored and enhanced the joint's seismic behavior, making this retrofitting strategy effective for seismic rehabilitation. By evaluating the post-damage retrofitting performance under cyclic loading, providing insight into failure mode transformation and seismic resilience improvement compared to conventional undamaged or non-retrofitted joints.

**Keywords:** Carbon fiber reinforced polymer; Galvanized iron fiber; Beam-column joint; Retrofitting.

## **1. Introduction**

Earthquakes have increasingly become a matter of concern in the last decades because of the significant damage and casualties they cause (Seifi et al. 2017). Beam column joints are particularly more vulnerable during seismic events, and the inelastic behaviour of beam-column joints is of special importance because they act as direct load transfer points in structures and undergo high inelastic demands. The dynamic effects of an earthquake or other event can cause these joints to crack, dislocate or fail, thus threatening the overall settlement of the structure (Maheswaran et al. 2022). Therefore, it is necessary to enhance the seismic behavior of such joints in order to alleviate the structural damage and improve the safety of structures under seismic excitation.

The retrofitting of weak or deteriorated reinforced concrete (RC) members due to corrosion, deterioration, or seismic need has been an increasingly popular rehabilitation alternative. Fiber reinforced polymer (FRP) among other retrofitting methods have been the most widely used because of their high strength to weight ratio, corrosion resistant and easy application. For instance, glass fiber reinforced polymer (GFRP) and carbon fiber reinforced polymer (CFRP) composites are used in strengthening work. Among them, CFRP has advantages in terms of its mechanical properties and durability, and it has therefore been widely used in global retrofit work (Del Zoppo et al. 2017). Studies found that the seismic behavior of old RC beam-column joints and the effectiveness of fiber-reinforced concrete (FRC) jacketing for strengthening. FRC significantly improves shear strength (by 50%) and energy dissipation (by 85%), preventing brittle joint failure (Ciro Del Vecchio et al. 2017). Galvanized iron (GI) fibers are used in concrete to enhance their mechanical properties, particularly improving strength, durability, and bond behavior. Their zinc coating provides a protective layer that reduces corrosion risk, making them suitable for reinforced concrete applications. The incorporation of GI fibers increases bond strength between rebar and concrete, as well as improves load-slip behavior, leading to more durable and reliable concrete structures (Islam et al. 2025). This study explores the cyclic behaviour of beam column joint with and without CFRP retrofitting in terms of hysteresis curve, energy dissipation, secant stiffness and ductility and establish an effective and economical natural aggregate concrete CFRP retrofitting method that can be applied to strengthen the damaged reinforced concrete (RC) structures, improving their seismic resilience.

## **2. Materials**

In this study, Portland composite cement (PCC) was used as the primary binder. The cement had a specific gravity of 2.85 kg/m<sup>3</sup>. Sylhet sand, was employed as fine aggregate with a fineness modulus (FM) of 2.92 and a water absorption capacity of 0.60%. Crushed stone was used as coarse aggregate, ensuring a well-graded aggregate blend to enhance packing density and mechanical interlock within the concrete matrix. The specific gravity of the coarse aggregate was measured at 2.87, with a unit weight of 1532 kg/m<sup>3</sup>.

The carbon fiber (Figure 1(a)) was mechanically tested following ASTM D3039, and tensile strength and elastic modulus was 4.05 GPa and 245 Gpa, respectively. Nominal thickness of the dry fabric was found to be 0.26 mm. To enhance the mechanical properties of the concrete, 15 mm long galvanized iron (GI) fibers (Figure1(b)) were incorporated as reinforcement, with a diameter of 0.5 mm and a maximum tensile strength of 370 MPa. GI fibers provides improved post-cracking behavior, ductility, and resistance to impact and fatigue (Ahmed et al. 2024).



Figure 1: (a) CFRP and (b) GI fiber.

### 3. Methodology

In this study, a sample with the size of 150 mm×150 mm×1500 mm (Figure 2(a)) is tested. The specimen is made from natural aggregate. Additionally, GI fiber at a level of 0.5% is used. The specimens experienced cyclic loading with a maximum drift of 6% or until failure occurs. A 70 kN axial load is applied continuously to the top end of the column. The damaged zones and cracks are identified and repaired before retrofitting. The CFRP retrofitting process involves applying a single layer of 200 gsm CFRP fabric with overlap according to ACI 440.2R-17 and fully covering the damaged region of the beam-column joint (Figure 2(b)).

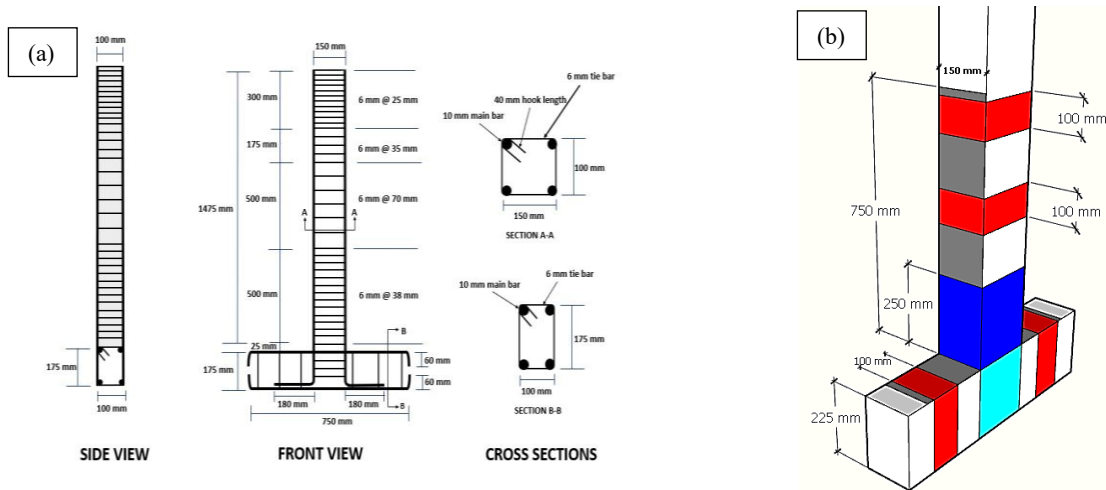


Figure 2: (a) Detailing of Sample, (b) schematic diagram of CFRP.

The preparation of concrete beam column joints for carbon fiber wrap application entailed several procedures to repair the beam column joint. First, the whole damaged regions of sample were investigated, and the loose concrete was removed using suitable tools. The damaged concrete was repaired by the application of micro-concrete restoring the vitality and strength to the damaged zones. After the micro-concrete was cured and set, the surface of the repaired places was grinded. After surface preparation, the CFRP wrap was applied. The CFRP was cured following the manufacturer's recommendations for the highest bonding strength. After curing, the retrofitted beam-column joint was tested under cyclic loading to evaluate its performance, as shown in Figure 3. The repair, followed by carbon fiber wrapping technique, improves the structural performance of the sample, and represents a strong solution to better performance under cyclic loading conditions.



Figure 3: Cyclic loading test setup.

#### 4. Result and Discussion

In the non-retrofitted beam-column joint, hairline cracks first appeared at service load, with widths of 0.05–0.1 mm. These cracks slowly grew to 0.1–0.2 mm at 1% drift, 0.2–0.3 mm at 1–2% moderate drift, and more than 0.5 mm at 3–4% drift (figure 4). The retrofitted specimen exhibited only two visible cracks, highlighting the improved crack control and enhanced ductility achieved through retrofitting.

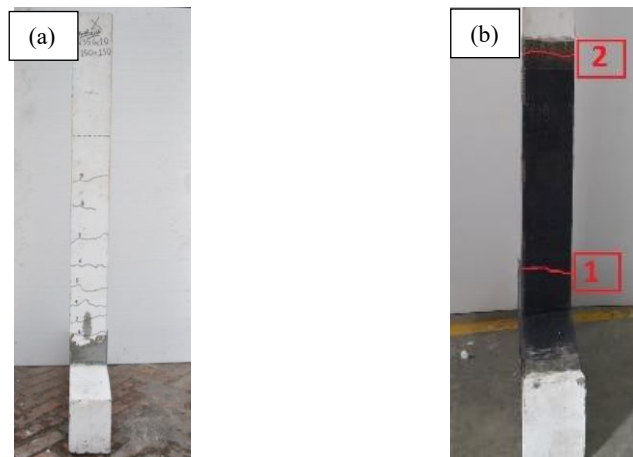


Figure 4: Cracks in: (a) non-retrofitted and (b) retrofitted samples.

The variation of hysteretic curves (Figure 5) of R-N35G10 (retrofitted) compared to N35G10 (without retrofitted) refers to the same pattern of ductile material during cyclic loading stage, however with distinct values of maximum load and displacement. The maximum load recorded for the R-N35G10 was 12.3 kN, and the minimum load observed was -14.68 kN. The retrofitted sample had wider load absorbing area, which means that the material could resist more tensile and compressive forces after the retrofit. This retrofitting enhanced its energy dissipation capacity and cyclic behaviour, as indicated by the hysteresis curve coverage. The maximum and minimum load in the normal sample was 13.34 kN and -13.74 kN for the N35G10. As observed in Figure 5, both samples show the same

behavior with regards to the general shape of the curve, which is the usual hysteresis type of response, as the material follows a loading-unloading cycle. By contrast, the retrofitted sample has a 15-20% better performance to resist the extreme load conditions, mainly in compression.

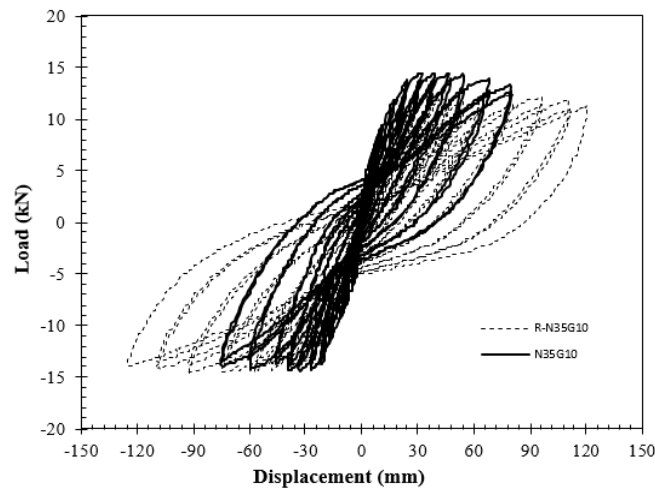


Figure 5: Hysteresis curve.

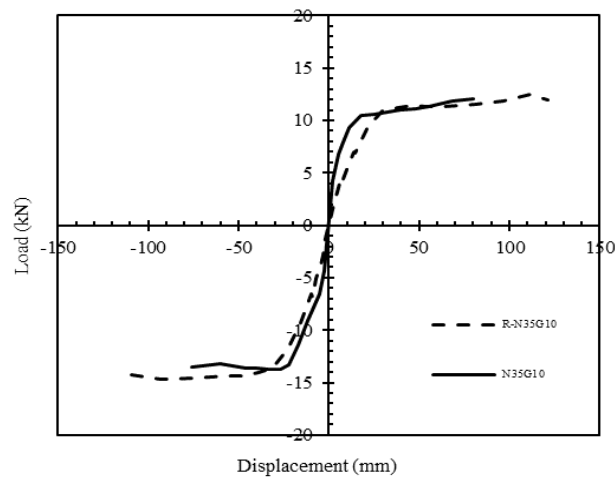


Figure 6: Skeleton curve.

The R-N35G10 (retrofitted) sample exhibited a significant enhancement in energy dissipation (Figure 7), starting at approximately 200 kN.m at 0% drift and reaching a peak value of 1,600 kN.m at 8% drift. In contrast, the N35G10 (non-retrofitted) sample, while following a similar trend, peaked at 1,400 kN.m at 6% drift. This indicates that retrofitting enhances the sample's capacity to absorb and dissipate energy during seismic loading, particularly at higher drift levels. Both samples began with a stiffness (Figure 8) of approximately 2 kN/mm at 0% drift, gradually reducing to 0.1 kN/mm by 8% drift. However, the R-N35G10 sample maintained slightly higher secant stiffness values at lower drift percentages, indicating that retrofitting provides an improvement in initial stiffness compared to the non-retrofitted sample.

The ductility index of two specimens i.e., retrofitted (R-N35G10), non-retrofitted (N35G10), is calculated, and it is 3.97 and 3.84, respectively. This means that the retrofit specimen is slightly more ductile and may deform to a greater extent prior to failure as compared to the non-retrofit specimen. The retrofitted material seems better able to deform plastically, which may be useful in applications that require flexibility and energy absorption (Seifi et al. 2017). The retrofitting of the R-N35G10

sample significantly improved its seismic performance, enhancing its ability to absorb energy and maintain stiffness under cyclic loading. These findings emphasize the potential benefits of retrofitting in improving the structural resilience of materials, particularly in applications subjected to dynamic loads, such as in seismic zones (C. Del Vecchio et al. 2018). The reasons for the reduced load-carrying capacity include inadequate anchorage of CFRP sheets, and suboptimal repair detailing that does not sufficiently account for combined load effects, all of which interrupt the development of full tensile force in the CFRP reinforcement and limit the joint's capacity (He et al. 2013).

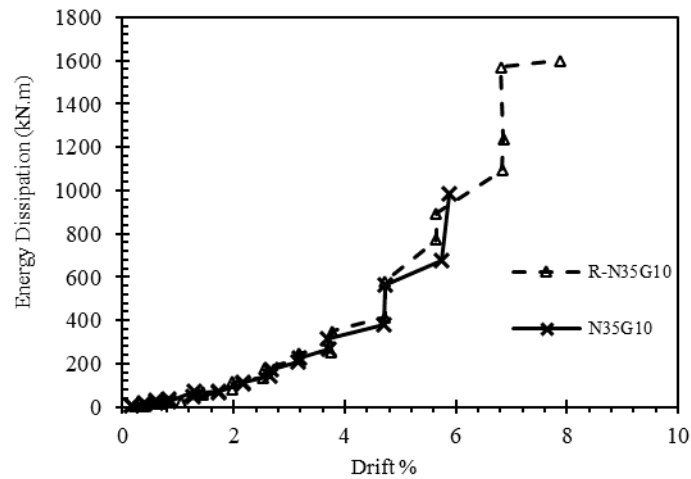


Figure 7: Energy dissipation curve

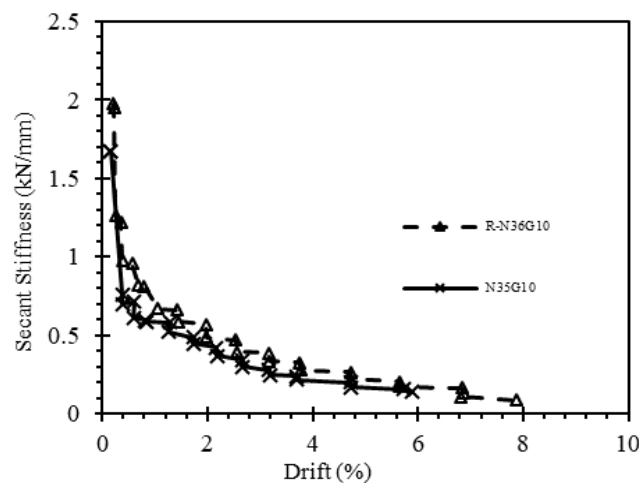


Figure 8: Secant stiffness curve

## 5. Conclusion

The experimental results revealed the following conclusions:

- A 15-20% increase of energy dissipation and 10-15% increase in stiffness for the retrofitted sample can be observed in comparison with the non-retrofitted sample, implying improved energy absorption and deformation.
- The retrofitted sample had a 5 to 10% increase in ductility, indicating better deformation potential before failing.
- The load-carrying capacity of the retrofitted sample was 5-10% less than that of the non-retrofitted one but was more effective under compressive forces.

Overall, retrofitting improved the sample's seismic performance in terms of energy dissipation, ductility, and stiffness.

#### **ACKNOWLEDGEMENTS**

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