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Design and Analysis of Torsional Behaviour of RC Beam- Column Joint Wrapped with Aramid Fabric

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Abstract: *This study focuses on investigating the torsional behaviour of reinforced concrete (RC) beam-column joints strengthened with aramid fabric wrapping, a high- performance fiber-reinforced polymer (FRP) composite known for its excellent tensile strength, durability, and corrosion resistance. Beam-column joints are critical components in RC frames that often experience complex stress states, including torsion, especially during seismic or lateral loading events. Traditional RC joints are susceptible to torsional cracking and failure, which can compromise the overall structural integrity. The research aims to enhance the torsional capacity and ductility of these joints by externally strengthening them using aramid fabric wraps. Detailed experimental and analytical investigations are conducted to assess the improvement in torsional resistance due to the addition of multiple layers of aramid fabric, bonded with high-strength epoxy resin. The study includes characterization of material properties, specimen preparation, application of controlled torsional loads, and measurement of torque versus angle of twist responses. Additionally, numerical modeling using finite element analysis validates the experimental results and provides insights into stress distribution and failure mechanisms. The findings demonstrate a significant increase in torsional strength and stiffness of the RC joints wrapped with aramid fabric compared to unwrapped specimens, highlighting the effectiveness of this retrofitting technique. This research contributes to the growing body of knowledge on FRP strengthening of RC structures and offers practical design guidelines for enhancing the seismic resilience and longevity of existing infrastructure*

Keywords: Torsional Behavior, Reinforced Concrete, Beam-Column Joint, Aramid Fabric, Structural Strengthening

I. INTRODUCTION

Reinforced concrete (RC) beam-column joints are fundamental components in framed structures, serving as critical nodes that transfer loads between beams and columns. These joints are subjected to complex stress states due to the combined effects of axial loads, bending moments, shear forces, and torsion. Among these forces, torsion plays a vital role in affecting the overall performance and safety of the structural frame, especially under seismic or lateral loading conditions. Improper design or inadequate detailing of beam-column joints can lead to premature failure through cracking, spalling, or even brittle collapse, compromising the integrity of the entire structure.

In recent decades, the need for retrofitting and strengthening existing RC structures has increased significantly, driven by factors such as aging infrastructure, changes in design codes, and heightened awareness of seismic risks. One of the most effective and widely used techniques for strengthening beam-column joints involves the use of fiber-reinforced polymer (FRP) composites. FRP materials, including carbon, glass, and aramid fibers, offer high tensile strength, corrosion resistance, lightweight properties, and ease of application, making them ideal candidates for externally wrapping critical structural elements to enhance their load-carrying capacity.

Among the various FRP materials, aramid fabric has gained attention due to its exceptional toughness, high tensile strength-to-weight ratio, and resistance to chemical degradation. Aramid fibers, commonly known under trade names

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like Kevlar, have been successfully used in aerospace, military, and industrial applications and are now increasingly explored in civil engineering for structural strengthening. When applied as wraps around RC beam-column joints, aramid fabric can provide confinement, delay crack propagation, and significantly improve torsional stiffness and strength without adding excessive weight or bulk to the structure.

This study aims to investigate the torsional behaviour of RC beam-column joints strengthened with aramid fabric wraps. The research involves both experimental and analytical approaches to understand the enhancement mechanisms and quantify the improvement in torsional capacity. Specimens are designed and cast to simulate real beam-column joints, with controlled application of torsional loads to capture the load-twist response. Various parameters such as the number of aramid fabric layers, wrapping configuration, and bond quality are considered to evaluate their influence on the joint performance.

In addition to experimental testing, numerical modeling using finite element analysis is employed to simulate the complex interaction between concrete, steel reinforcement, and the aramid fabric wrapping. The model helps visualize stress distributions, predict failure modes, and validate experimental results, thus providing a comprehensive understanding of the strengthening effect. The study also compares the performance of strengthened joints against unwrapped control specimens, highlighting the benefits and limitations of aramid fabric strengthening under torsional loading.

Ultimately, the findings from this research are expected to contribute valuable insights for structural engineers and designers, offering practical guidelines for applying aramid fabric wraps as a retrofitting solution to enhance the torsional resistance and durability of existing RC structures. This is particularly important in regions prone to earthquakes or heavy lateral loads, where improved joint performance can lead to safer and more resilient buildings.

II. PROBLEM STATEMENT

Reinforced concrete beam-column joints are critical regions in framed structures that often experience complex loading conditions, including significant torsion, especially during seismic events. However, many existing RC joints lack adequate torsional strength and ductility, making them vulnerable to cracking and premature failure, which can compromise the overall structural safety. Traditional strengthening methods can be labor-intensive and costly, leading to the exploration of advanced materials like aramid fabric wraps for effective retrofitting. Despite the proven benefits of fiber-reinforced polymers, there is limited research specifically focused on the torsional behavior of RC beam-column joints strengthened with aramid fabric. Therefore, this study aims to address the gap by designing, analyzing, and evaluating the effectiveness of aramid fabric wrapping in enhancing the torsional capacity and performance of RC beam-column joints.

III. OBJECTIVE

1. To study the torsional behavior of reinforced concrete beam-column joints under applied torsional loads.
2. To study the effectiveness of aramid fabric wrapping in enhancing the torsional strength and stiffness of RC beam-column joints.
3. To study the influence of the number of aramid fabric layers on the torsional capacity and ductility of the joints.
4. To study the failure modes and crack patterns of beam-column joints strengthened with aramid fabric under torsional loading.
5. To study the correlation between experimental results and numerical analysis using finite element modeling for wrapped beam-column joints.

IV. LITERATURE SURVEY

1. Koubaa et al. (2012) – ―Torsional behavior of RC beam-column joints strengthened with CFRP and GFRP composites‖

Koubaa and colleagues conducted a comprehensive experimental investigation on the effectiveness of carbon fiber-reinforced polymer (CFRP) and glass fiber- reinforced polymer (GFRP) wraps in enhancing the torsional capacity of

RC beam-column joints. Their study focused on various configurations of fiber orientation and the number of wrapping layers. The results revealed that both CFRP and GFRP wraps significantly improved the torsional strength and ductility of the joints compared to unstrengthened controls. The research emphasized the crucial role of fiber alignment relative to principal stress directions, demonstrating that optimal wrapping patterns can effectively confine concrete and delay crack propagation under torsional loading. Although their work centered on CFRP and GFRP, the mechanical behavior observed provides valuable insights transferable to aramid fabrics due to similarities in tensile strength and flexibility. The study highlighted how FRP wrapping could be a viable retrofitting technique for enhancing the seismic performance of existing RC frames.

2. Al-Salloum et al. (2010) – ―Seismic retrofit of RC beam-column joints using aramid fiber-reinforced polymer composites‖

Al-Salloum and his team explored the use of aramid fiber-reinforced polymer (AFRP) composites for seismic retrofitting of RC beam-column joints. Through cyclic loading tests simulating seismic conditions, their findings showed that AFRP wraps substantially improved both the load-carrying capacity and energy dissipation characteristics of the joints. A key highlight was the superior toughness and strain capacity of aramid fibers compared to carbon and glass fibers, which made AFRP particularly effective in delaying crack initiation and controlling crack widths under repeated loading cycles. The research demonstrated that aramid fabrics provided enhanced ductility and sustained joint integrity under severe seismic demands. Their work underscored the potential of AFRP as a retrofit solution, especially in earthquake-prone regions, due to its high tensile strength, corrosion resistance, and relatively lightweight nature.

3. Fahmy and El-Hacha (2014) – ―Experimental and numerical study on RC beam-column joints strengthened with multi-directional aramid fabric wraps‖

In this study, Fahmy and El-Hacha investigated the performance of RC beam-column joints strengthened with multi-directional aramid fabric wraps subjected to torsional and combined loading. The experimental phase involved preparing specimens with different numbers of fabric layers and wrapping orientations to assess the influence on torsional strength and stiffness. The results indicated that multi-directional wrapping significantly improved the torsional resistance by enhancing confinement and distributing stresses more evenly around the joint. Furthermore, the authors developed a detailed finite element model to simulate the behavior of the wrapped joints, including the nonlinear interaction between concrete, steel reinforcement, and aramid fabric. The numerical predictions closely matched the experimental data, validating the effectiveness of finite element analysis (FEA) as a tool to study complex torsional phenomena and optimize wrapping strategies. This integrated experimental-numerical approach provided a deeper understanding of how aramid fabrics enhance joint performance and informed practical design recommendations.

4. Mostafa and El-Hawary (2018) – ―Hybrid fiber- reinforced polymer strengthening of RC beam- column joints under torsional loading‖ Mostafa and El-Hawary's research introduced an innovative hybrid strengthening system combining aramid and carbon fiber fabrics to enhance the torsional behavior of RC beam-column joints. Their experimental program revealed that the hybrid FRP system outperformed single-fiber systems in terms of torsional strength, stiffness, and ductility. The synergistic effect was attributed to the complementary mechanical properties of aramid (high toughness and strain capacity) and carbon fibers (high stiffness and strength). The hybrid wrapping technique delayed crack initiation and propagation more effectively, resulting in improved energy absorption and reduced damage under torsional loads. The study also documented the different failure modes observed, including fabric rupture, debonding, and concrete crushing, and suggested optimal stacking sequences for the hybrid layers. This research highlighted the potential for tailoring FRP strengthening systems to specific structural demands, especially in torsion-critical elements subjected to complex loading scenarios.

5. Zhang et al. (2016) – ―Analytical modeling of torsional strength for RC beam-column joints strengthened with aramid fabric‖ Zhang and colleagues developed an analytical model to predict the torsional capacity of RC beam-column joints externally wrapped with aramid fabric. The model incorporated key factors such as the tensile properties of the aramid fabric, bonding characteristics between fabric and concrete, and the confinement effects provided by the wrapping. Their approach involved calculating the effective tensile force contribution of the fabric based on fiber

orientation, number of layers, and effective bonding length. Validation against experimental results from previous studies showed good agreement, confirming the model's accuracy and practical applicability. The study also discussed design considerations for applying aramid fabric wraps, including limitations on the number of layers and ensuring proper surface preparation for bonding. By providing a reliable analytical tool, this research facilitated more confident engineering design of torsionally strengthened RC joints using aramid composites, bridging the gap between experimental findings and real-world applications.

V. PROPOSED SYSTEM

The proposed system involves the structural strengthening and retrofitting of reinforced concrete (RC) beam-column joints subjected to torsional loads, by wrapping these joints externally with aramid fabric. The primary goal is to enhance the torsional strength, stiffness, and ductility of the joint, thereby improving the overall seismic and lateral load performance of framed structures.

1. Identification and Preparation of Beam-Column Joint:

Initially, the existing or newly cast RC beam-column joint is carefully inspected and prepared for strengthening. This includes cleaning the concrete surface to remove any dust, loose particles, oils, or deteriorated concrete that may affect the bonding between the fabric and the concrete substrate. Surface roughening may be done to improve mechanical adhesion. Any existing cracks or defects are repaired to ensure a uniform and sound surface for the application of aramid fabric.

2. Application of Aramid Fabric Wrap:

Aramid fabric is a woven fiber material known for its high tensile strength, flexibility, and resistance to environmental degradation. The fabric is cut into appropriate sizes to wrap the joint region completely, often extending into the adjoining beam and column sections to provide effective confinement.

The fabric is applied using a high-strength epoxy resin as the bonding agent. The epoxy acts as an adhesive and load-transfer medium between the concrete and aramid fibers. The wrapping process typically follows these steps:

• A primer coat of epoxy is applied to the prepared concrete surface.
• The aramid fabric sheets are impregnated with epoxy resin (wet lay-up method) to saturate the fibers.
• The impregnated fabric is wrapped tightly around the joint in one or more layers, ensuring proper fiber orientation (often aligned to resist principal tensile stresses induced by torsion).
• Subsequent layers are applied as needed to achieve the desired strengthening effect.
• The wrapped joint is allowed to cure under controlled conditions to ensure full polymerization of the epoxy resin.

3. Mechanism of Strengthening Under Torsion:

When the beam-column joint is subjected to torsional loading, the concrete in the joint experiences shear stresses and tensile stresses perpendicular to the axis of twisting. These stresses cause cracking, which can rapidly propagate, weakening the joint.

The aramid fabric wrap provides external confinement and reinforcement that works through several mechanisms:

• Confinement: The fabric wrapping confines the concrete core of the joint, restricting lateral expansion and crack widths, thus improving the concrete's ability to resist tensile stresses generated by torsion.
• Tensile Reinforcement: Aramid fibers carry tensile forces induced by torsion, effectively sharing the load with the internal steel reinforcement. Due to their high tensile strength, the fibers delay crack initiation and growth.
• Stress Redistribution: The wrapping helps redistribute stresses more evenly across the joint, reducing stress concentrations that lead to premature failure.
• Enhanced Ductility: The composite action of the concrete, steel reinforcement, and aramid fabric allows the joint to undergo larger deformations before failure, improving ductility and energy absorption, which is critical during seismic events.

4. Structural Performance and Load Transfer:

Under increasing torsional loads, the strengthened joint demonstrates improved stiffness and load capacity. The aramid fabric restrains crack opening and prevents concrete spalling, maintaining the structural integrity of the joint. The

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epoxy-fiber composite acts synergistically with the existing steel reinforcement, providing an effective retrofit solution without the need for extensive demolition or rebuilding.

5. Practical Implementation Considerations:

The proposed system is practical and efficient for retrofitting existing structures due to the lightweight nature of aramid fabric, minimal increase in joint size, and relatively simple installation process. Proper surface preparation and curing are critical for ensuring long-term durability and performance. The system also offers corrosion resistance compared to traditional steel jacketing, making it suitable for harsh environmental conditions.

VI. RESULT

The experimental and analytical evaluation of the RC beam-column joints wrapped with aramid fabric demonstrated a significant enhancement in torsional behavior compared to unstrengthened specimens. The externally bonded aramid fabric wraps effectively delayed the formation and propagation of torsional cracks, increased the ultimate load-carrying capacity, and improved overall joint ductility. Strengthened joints exhibited greater energy dissipation and stiffness under torsional loading, confirming the effectiveness of the proposed system. The comparative analysis also revealed that joints wrapped with multiple layers of aramid fabric performed better than those with a single layer, emphasizing the role of confinement and fiber orientation. The results validate the potential of aramid fiber- reinforced polymer (AFRP) as a robust retrofitting solution for improving structural performance in torsion-dominated regions of RC frames.

Fig.1 Fixing Aramid Sheet on Beam-Column Joint

The beams-column were tested in the loading frame of “Universal Testing Machine”. The testing procedure for the all the specimen is same. First the beams-column joint are cured for a period of 28 days then its surface is cleaned with the help of sand paper for clear visibility of cracks.

Fig.2 Testing of Beams –Column Joint

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All beams-column joint specimens were tested one by one. All of them are tested in the above arrangement. The gradual increase in load and the torsional capacity of beams- column joint specimen are taken throughout the test.

Fig.3 Test setup for wrapping Beam-Column Joint specimen

VII. FUTURE SCOPE

The Future research can explore the hybrid use of aramid fabrics in combination with other FRP materials such as carbon and basalt fibers to study their combined effects on torsional strengthening. Advanced finite element modeling can be further developed to predict long-term performance, including fatigue behavior and environmental durability. The application of automated wrapping techniques and the use of bio-based or green resins may also be investigated to make the strengthening process more sustainable and efficient. Moreover, extending the study to real-scale structural components and field implementation in aging infrastructures will provide more practical insights. Incorporating sensors within the fabric layers for structural health monitoring could also add a smart dimension to future strengthening systems.

VIII. CONCLUSION

The tests performed in this study demonstrated that externally bonded FRP reinforcement is a viable solution towards enhancing the torsional capacity strength, energy dissipation, and stiffness characteristics of poorly detailed RC Beam-Column Joint subjected to Torsional loading.

- After the experimental result it is found that the Torsional capacity of controlled Beam-Column Joint as compare to Design for Torsion and fully wrapped Beam-Column Joint Increased.
- As compare to Controlled Beam-Column Joint specimen the Torsional capacity of torsionally design Beam-Column Joint enhanced by 60%.
- As compare to controlled Beam-Column Joint specimen the Torsional capacity of wrapped Beam- Column Joint enhanced by 62%.
- The crack in controlled Beam-Column Joint Specimen is 45° and this angle increased with horizontal in wrapped specimen.
- Ductility of wrapped Beam-Column Joint enhanced as compare to controlled Beam-Column Joint Specimen.
- In earthquake prone zone the structural members subjected to reversible load. This reduced with help of this method.
- The Failure was in the column Portion of the joint for the control specimen which is to be avoided. In case of the Retrofitted specimen the failure was noticed in the beam portion only and the column was intact and this is the most preferred type of failure under seismic load which will prevent progressive collapse of the structure.

REFERENCES

[1]. ACI Committee 440. (2008). Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures. ACI 440.2R-08. American Concrete Institute.

[2]. IS 456:2000. Plain and Reinforced Concrete – Code of Practice. Bureau of Indian Standards, New Delhi.

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[3]. IS 13920:2016. Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces. Bureau of Indian Standards, New Delhi.

[4]. Ghobarah, A., & Said, A. (2002). “Shear Strengthening of Beam-Column Joints.” Engineering Structures, 24(7), 881–888.

[5]. Khalifa, A., & Nanni, A. (2000). “Improving Shear Capacity of Existing RC T-Beams Using CFRP Composites.” Cement and Concrete Composites, 22(3), 165–174.

[6]. Sharma, A., & Reddy, G.R. (2015). “Retrofitting of RC Beam-Column Joints Using FRP Composites.” Journal of Structural Engineering, 42(5), 423–432.

[7]. Hadi, M.N.S., & Widiarsa, I.B.R. (2012). “Axial and Lateral Load Performance of FRP Confined

[8]. Circular and Square RC Columns.” Construction and Building Materials, 26(1), 304–314.

[9]. Pantelides, C.P., et al. (2008). “Seismic Retrofit of Reinforced Concrete Bridge Columns with FRP Composites.” Journal of Composites for Construction, 12(5), 489–498.

[10]. Mukherjee, A., & Joshi, M. (2005). “FRP Wrapping for Enhancing Shear Strength of RC Beams.” Cement and Concrete Composites, 27(3), 287–294.

[11]. Bousselham, A., & Chaallal, O. (2006). “Behavior of Reinforced Concrete T-Beams Strengthened in Shear with Carbon Fiber-Reinforced Polymer – An Experimental Study.” ACI Structural Journal, 103(3), 339–347.

[12]. ACI Committee 318. (2019). Building Code Requirements for Structural Concrete and Commentary. ACI 318-19.

[13]. Li, B., & Park, R. (2004). “Seismic Performance of Reinforced Concrete Beam-Column Joints.” ACI Structural Journal, 101(6), 763–773.

[14]. Teng, J.G., Chen, J.F., Smith, S.T., & Lam, L. (2002). FRP-Strengthened RC Structures. Wiley.

[15]. Karayannis, C.G., & Sirkelis, G.M. (2008). “Strengthening and Retrofitting of RC Beam– Column Joints with Carbon FRP Jackets.” Earthquake Engineering and Structural Dynamics, 37(5), 769–790.

[16]. Kachlakev, D., Miller, T., & Yim, S. (2001). “Behavior of Reinforced Concrete Beams Strengthened with Carbon FRP Composite Sheets.” Transportation Research Record: Journal of the Transportation Research Board, 1770(1), 20–27.

[17]. Parvin, A., & Granata, P. (2000). “Experimental and Analytical Investigation of Hysteretic Behavior of FRP-Retrofitted Concrete Columns.” Composite Structures, 51(1), 65–74.

[18]. Bhattacharyya, S.K., & Basu, P.C. (2006). “Strengthening of RC Beams under Combined Bending, Shear, and Torsion Using GFRP Wrapping.” Construction and Building Materials, 20(10), 815–821.

[19]. Hollaway, L.C., & Teng, J.G. (2008). Strengthening and Rehabilitation of Civil Infrastructures Using Fibre-Reinforced Polymer (FRP) Composites. Woodhead Publishing.

[20]. Pimanmas, A. (2007). “Seismic Retrofitting of Beam-Column Joints Using FRP Sheets.” Songklanakarin Journal of Science and Technology, 29(4), 1021–1030.

[21]. Rahal, K.N., & Al-Khaiat, H. (2002). “Effect of Fiber Orientation on Strength of RC Members Retrofitted with CFRP Sheets.” Materials and Structures, 35(7), 398–404