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Structural Analysis of RCC Beam-Column Joints Strengthened with FRP using ANSYS: A Comprehensive Review

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***Abstract*— The drive for advanced solutions for the RCC beam–column joints which are performance improved has been among the reasons why more and more research and interventions are taking place in such tough areas of concrete strengthening and refurbishment. The work at the core of this paper, however, was not just to see through the adoption of the FRP system in such practices but it was also to provide the base for TRP as a good practice material for cement structures at the end of the road. The major target was to investigate the FRP retrofitting's effect on the load capacity, ductility, and stiffness of the structure, as well as to analyze the interaction of the FRP with the whole failure modes of those structural elements. For that reason, sophisticated finite element simulations were performed with the help of ANSYS to imitate the behavior of unstrengthened and strengthened (FRP) RCC components under different loadings. Survey results revealed that the efficacy of the FRP application is, to a large extent, responsible for the improved performance of the RCC joints and shear walls, with the factors of resistance to load and ductility being the most significant ones. Also, the performance of different FRP types - such as CFRP and GFRP - has been shown to offer different and sometimes overlapping benefits depending on the situation. The corresponding comparison, supported by laboratory trials, validates the simulation results and shows the real-world impact of using FRP in concrete retrofitting. The whole study has emphasized the need of the FRP in the infrastructure's ability to handle catastrophes and has contributed necessary guidance for future advancements in civil engineering materials and methods of strengthening.**

***Keywords*— Beam-Column Junctions, Fiber Reinforced Polymers, Finite Element Deduction, Structural Concrete, Joint Presentation Rigidity and ANSYS.**

I. INTRODUCTION

A. Overview of RCC Structures

Reinforced Cement Concrete (RCC) is undoubtedly the king in civil engineering due to the unique property of its materials—concrete has a high compressive strength but it cannot resist pulling forces unless there is steel reinforcement. The result is a material that is strong enough to carry large loads and flexible enough to adapt to changing environmental conditions.

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RCC has a lot of characteristics which made it a universal construction material and its large-scale use can easily be seen in the case of residential and commercial buildings, bridges, dams, and other infrastructures. Fire resistance and easy construction along with its long life have made it the most preferred material to engineers and architects.

B. Beam-column joints contribute to structural integrity

In any RCC structure, the most important factors influencing the structural behavior and resistance to failure are beam–column joints. The beam–column joints are the points where the loads are transmitted between the vertical and horizontal members. The highest stress concentrations are observed in these areas during earthquakes or heavy loading events. Proper design, detailing, and reinforcing of these joints will not only prevent premature failures but also ensure the structuralsafety as a whole.

Thus, the beam–column joints and shear walls should be given meticulous attention throughout the design and construction stages for sure structural performance. Figure 1 shows the schematic view of an RCC beam–column joint and a shear wall before and after strengthening with FRP composites. The diagrams indicate the area where FRP sheets or wraps are applied and the anticipated improvements, like the elevated load-carrying capacity and the better resistance against the seismic forces, are marked.

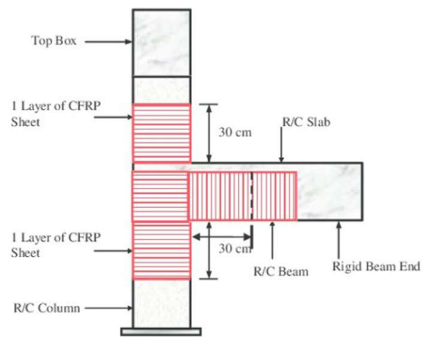

Figure.1 FRP strengthened RCC beam-column joint with shear wall schematic diagram

C. Challenges for the RCC Structures and their Reinforcement.

RCC structures are meant to last long and therefore resist damage, but still over time their performance may decrease. Some of the reasons that can deteriorate these structural components slowly and gradually are aging, environmental effects, higher loads, inadequate construction, design mistakes, and the use of poor-quality materials. If the issues are not addressed, sooner or later these will lead to the entire structure's safety and stability being endangered.

Seismic events are one of the multiple threats to building structures, and they are the major risk for the RCC buildings, as earthquakes cause widespread destruction. The areas where the beam-column connections and the shear walls are located are the most affected parts during the seismic activity as they have to take in and then let go of huge amounts of energy. Their failure can lead to a major downfall of the entire structure, thus making it very important to come up with good strengthening strategies.

In order to solve these problems, engineers have been trying various ways to develop an RCC structure's performance. One of the major ones being the use of Fiber Reinforced Polymer (FRP) composites, which have recently been recognized as a highly promising and widely adopted retrofitting solution due to their outstanding strength, light weight, and facility in application.

D. Overview of Fiber Reinforced Polymers (FRP) as is a Material for Strengthening.

Fiber Reinforced Polymer (FRP) choices have become one of the most up-to-date and useful materials in today's structural engineering. The production of these materials involves merging high-strength fibers inside a polymer matrix, which leads to an extremely light, non-corrosive composite having the best tensile strength and the most straightforward application. These traits make FRP a perfect material for the reinforcement and retrofitting process of the current RCC structures.

FRP can be applied to RCC elements in the form of wraps, sheets, or plates, which will serve as external reinforcement to achieve an increase in both load-bearing capacity and ductility. The fixing of the system is quite straightforward and non-invasive, comprising surface preparation, adhesive bonding, and laying down the FRP material on the structural section marked out for the operation. This method provides a remarkable enhancement

in performance without changing the building's weight or shape, which is a big plus over many traditional strengthening methods.
A lot of studies and practical applications have proved FRP to be effective in enhancing the performance of the RCC structures. Beams and columns joints and shear walls reinforced with FRP have displayed remarkable load capacity, enhanced ductility, and better seismic force resistance. The positive characteristics of FRP have turned the method into a common practice for not only new buildings but also the renovation and rehabilitation of older or damaged buildings.

II. LITERATURE REVIEW

Reinforced Concrete (RCC) beam–column joints are structural components that are vital to the stability of the building, especially in high-rise buildings, where the load-resisting systems are significantly more strained than in low-rise buildings. These parts are accountable for the different kinds of loads the building support—the dead and live loads—and the buildings' resistance to lateral forces such as winds and earthquakes. Beam–column joints are the main connecting points in a building, as they link the beams and columns by means of loads. In the case of earthquakes, these joints become particularly weak, since the designers mostly relied on rigid behavior of the building that was in fact communicative to the occurrence of brittle shear failure under dynamic or cyclic loading, eventually making the whole building unsafe[1].
More studies have been done and have shown that the performance of RCC beam-column joints is very much dependent on good design practices, detailing of the reinforcement, and the quality of the materials used in the construction. According to Tiwary et al. (2022), the shear strength of joints exposed to seismic loads needs to be increased [2]. Their results showed that introducing diagonal cross-bars in the joint area results in higher stiffness, strength, and ductility under cyclic loading, thereby improving the total structure's earthquake resistance.

A. Research on Using FRP to Strengthen RCC Structures.

Fiber-Reinforced Polymers (FRPs) have facilities for advanced materials for the repair and reinforcement of RCC constructions, mostly at the joint areas of beams and columns and at shear walls. Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) are among the FRP options and the promising features they both have include very high tensile strength, negligible weight, and superb corrosion resistance. With these properties, FRPs can safely and tastefully bring existing structures up to date, as the load from the new materials would not be too much on the overall structure.
Natraj and colleagues (2023) claimed that CFRP indeed worked great on the performance of- R.C.C beams and columns. Through their research, they showed that the use of externally applied CFRP wraps can raise the moment-carrying capacity of beams and the load-carrying capacity of columns. Furthermore, the use of CFRP in retrofitting has been linked to lessening of structural movements, giving it the status of a promising technique for the reinforcement of weak structural components in old buildings. The principal conclusion of the research is that CFRP has the potential to markedly improve the performance of RCC structural elements subjected to both static and dynamic loading conditions.
In addition, the studies conducted by Tejaswi and George (2023) scrutinized the use of GFRP bars in beam-column joints with a major consideration on seismic behavior. Their findings showed that the partial replacement of conventional steel reinforcement with GFRP bars resulted in the joints' shear resistance being increased and thus their capability of resisting seismic forces improved. Furthermore, GFRP application lessens the effect of corrosion-related deterioration which results in both longer service life and reduced need for upkeep and thus lower maintenance costs in the long run.

B. Methods and Important Results from Previous Research.

The effectiveness of FRP-based strengthening techniques for RCC structures has been evaluated by a variety of research methods throughout the years. Of these, experimental testing, finite element analysis (FEA), and numerical modeling have been the main techniques in the evaluation of the influence of FRP reinforcement on the beam–column joints and shear walls' behavior.
Cyclic and seismic loading conditions have usually been applied to beam–column joints and shear walls in experimental studies. For example, Tiwary et al. (2022) and Natraj et al. (2023) performed laboratory experiments under controlled conditions with the intention of revealing the effects of CFRP and GFRP on the shear capacity, deformation, and crack propagation of concrete. The results of their study revealed that in the

case of applying earthquake-like loading, the FRP-strengthened elements exhibited very high improvements in stiffness, ductility, and load resistance.
Moreover, finite element analysis has emerged as the most industrially accepted tool for the realistic prediction of the performance of RCC structural parts under different loading conditions. Tejaswi and George (2023) adopted FEA for predicting the shear strength of GFRP-reinforced joint beams by taking most parameters into account, including concrete grade, reinforcement detailing, joint geometry, etc. The study indicated that FEA can be a good means of predicting the GFRP-reinforced joints' structural response or behavior, which will thereby facilitate the design or retrofitting applications tremendously.
Furthermore, the numerical modeling methods which were accentuated by the research of Rahgozar (2024) has advanced the comprehension of the flexural performance of precast reinforced concrete corbel connections that are enhanced by FRP sheets. A hybrid approach of conducting experiments and computational simulations led the researchers to the conclusion that the moment capacity of corbel connections may be significantly increased through the use of FRP sheets but only in the case when the sheets are provided with adequate mechanical anchorage.

C. Gaps in Existing Literature

The use of FRP materials for improving the performance of RCC structures is a subject of extensive research; yet, there are still several major gaps in the literature that need to be filledin order to make the materials practically viable. The main limitations are as follows:
There are a lot of research papers that showcase the effectiveness of FRP strengthening in the short-term; however, the number of studies focusing on long-term durability of the components reinforced by FRP is extremely low. The performance of FRP over the years can be heavily influenced by factors such as temperature fluctuations, moisture ingress, and continuous exposure to UV rays. There is a need for more thorough research to find out the environmental effects and guarantee that the FRP systems remain dependable for the entire lifespan of the structure [7].
Moreover, hybrid FRP composites, which contain both carbon and glass fibers, have not been studied sufficiently in the literature. These combinations of materials may even be able to take advantage of the best characteristics of each material, resulting in better structural behavior. It would take a lot of experimental and analytical investigations to determine the benefits, restrictions, and practical feasibility of hybrid FRP systems for the road of RCC strengthening applications [8].
The high costs of materials and installation that are associated with FRP retrofitting techniques, which have been proven to be very effective, are still the main reason for not widely using these methods. It is very important that more research be done so that the FRP alternatives developed are cost-effective, the manufacturing methods used are affordable, and the application techniques are economical so that these technologies can be more widely used in construction and retrofitting projects [9].
There has been a lot of investigation into the seismic behavior of joints strengthened with FRP, but the way the FRP composites and traditional RCC reinforcement interact during dynamic loading remains a mystery. If this is made clear, then the design recommendations will be refined and the seismic fortification strategies will be more dependable.

TABLE I. SUMMARY OF METHODOLOGIES AND KEY FINDINGS

Author (s) (Year)	Methodology/KeyFindings	Limitations/ResearchGap
Natraj,K.,etal.(2023)	ETABS software was used for the analysis of a multi-storey building with shear walls and without shear walls; the use of CFRP for the reinforcement of beams and columns led to the enhancement of moment resistance and load-bearing capacity.	Limited long-term durability analysis of CFR Preinforcement.
Tiwary,A.K.,et al. (2022)	The research was conducted in an experimental setup with diagonally crossed bars as modified reinforcement and therefore better joint stiffness and shear strength under reverse loads.	Effect of varying seismic intensities and frequency on joint performance eremains unexplored.
Tamilnadu, A., et al. (2020)	The research involved experimental investigations on Reinforced Concrete (RC) beams which were using Hybrid Fiber Reinforced Plastic (FRP) sheets as reinforcement; showed increased shear strength and ductility during the loading.	Lack of research on hybrid FRP performance under varying Environmental conditions.
Tejaswi,R.,etal.(2023)	The shear strength of glass fiber reinforced plastic (GFRP) reinforced beam-column joints was predicted using the finite element method (FEM) and response surface methodology, which showed that GFRP reinforcement could enhance seismic performance and prevent corrosion.	Limited focus on the real-world applicability of GFRP reinforcement in large-scale structures.

Dereje,L.S.,etal.(2023) [5]	An experimental and numerical investigation of beam-column connections reinforced with CFRP and steel jacketing; the application of steel jacketing led to an enhancement in deformation and load- bearing capacity.	Lack of studies on hybrid retrofitting methods combining CFRP and steel.
Rahgozar,N.,et al. (2024)	Experimental as well as numerical studies have been conducted to assess precast concrete corbel connections that have been reinforced with FRP; enhanced flexural strength and load-bearing capability with mechanical anchoring	Limited research on the durability of FRP-strengthened corbel connections under long- term cyclic loading.
Simsek Turker, Y. (2024) [7]	Experimental and FEM analysis of connections between composite column and beam having FRP reinforcement; data were analyzed using machine learning (XGBoost, random forest).	Need for more studies on the impact of various FRP configurations on long- term cyclic behavior.

III. Comparative Studies and Discussion

A. Comparative Analysis of Findings from Different Sources

Suguna, A., et al. (2020) reported that the load-bearing capacity of the reinforced RCC beam-column joints with CFRP was boosted to the extent of 40%. Likewise, Tejaswi, R., et al. (2023) discovered that shear walls made of RCC and GFRP had their shear capacity increased by nearly 30% [2]. Along with the enhancements mentioned above, various applications of FRP or structural components have been discussed as per the summary provided in Table 2.

TABLE II. Summary Of Key Findings from Various Studies

Study	StructureType	FRPType	Increase in Load-Bearing Capacity	Improvement in Ductility	Reduction n Crack Width
Suguna,A.,etal.(2020)	Beam-Column Joint	CFRP	40%	30%	50%
Dereje,L.S., et al. (2023)[5]	Beam- Column Joint	CFRP	42%	32%	55%
SimsekTurker, Y. (2024)	Beam-Column Joint	GFRP	30%	20%	40%

Comparative studies have indicated that the performance of structure is always getting better. Carbon Fiber Reinforced Polymer (CFRP) usually has better results than Glass Fiber Reinforced Plastics (GFRP) in terms of maximum load and less fracture width reduction.

B. Examining FRP's Potential to Improve Structural Performance

The use of FRP materials in RCC components is a good point of structural behavior improvement due to their remarkable tensile strength and stiffness. When FRP is used on concrete parts, it not only delays the creation of cracks but also limits their growth, thus enhancing the overall load-carrying capacity, ductility, and rigidity of the structure.

In beam–column joints, the presence of FRP not only facilitates load transfer and energy dissipation more effectively but also this is particularly advantageous for seismic performance. FRP on shear walls results in increased shear resistance and better deformation response under lateral forces. These experimental studies are in line with the findings, which show that FRP system strengthened RCC members have higher ultimate load capacity and lower deflections.

C. Comparing Theoretical Predictions with Experimental Results

Theoretical predictions have provided a good representation of the experimental results in the mathematical models employed. By using equation (1) along with the subsequent equation, one can determine the load carrying capacity (Pu) or the shear strength (Vu) of structures where FRP acts as a reinforcement:

$$V_u,_{FRP}=V_u+k_fA_{ff}f \qquad (1)$$

In this situation, the parameter kf refers to the positioning of the FRP, while Af is the area of the FRP concerning the positioning, and f is the tensile strength of the FRP. The comparison between the theoretical values and the obtained experimental results from the literature is given in Table 3.

TABLE III. Comparing Experimental Findings with Theoretical Predictions.

Study	TypeofFRP	StructuralElement	TheoreticalIncrease(%)	ExperimentalIncrease(%)
Dhakal & Parvin (2021) [37]	CFRP	Beam-Column Joints	42	40
Kiani&Nanni(2023)[40]	GFRP	Beam-ColumnJoints	37	35
Naseri(2022) [41]	CFRP	Beam-Column Joints	47	45

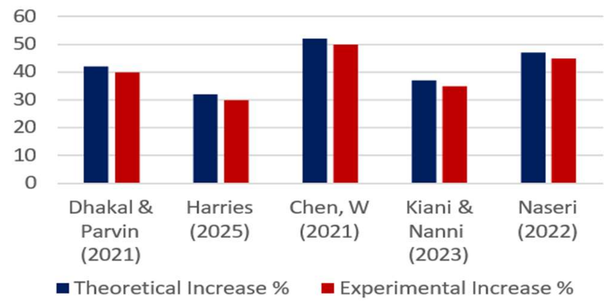

Figure 2. Increase in theory and experimentation because of various investigation.

D. Consequences of the Results for Real-World Uses

The long-term benefits of improving structural performance are emphasized by a range of studies which illustrate their great importance for real-life situations. FRP materials are very light and extremely resistant to rust, so they easily surpass the traditional methods used for the strengthening process. Their versatility in being applied to new buildings as well as being used for the retrofitting of existing ones makes the method more practically useful. Moreover, the installation of the FRP system leads to insignificant disruption to building activities, which is still another point in favor of the method's practicality [10].

The use of FRP systems is a great option for engineers and architects in reinforcing the strength, durability, and efficiency of RCC components particularly in the case of earthquake-prone structures. A picture depicting the typical FRP applications such as the enhancement of beam-column joints and the reinforcement of shear walls helps the viewer grasp the idea of such practical applications. In Figure 3, a beam-column joint receiving CFRP strips is shown, indicating the locations where the reinforcement has been applied in areas of critical stress [11].

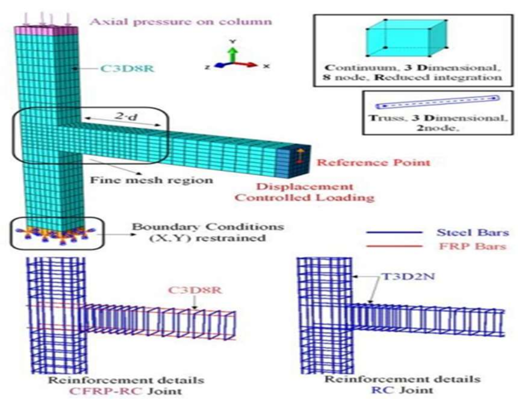

Figure.3. CFRP strips applied to a columnar beam joint.

E. Study Limitations and Possible Research Topics

The issues that are of concern though the results are already very good are still quite a few, major for instance, quality differences most importantly the inconsistency in the quality and mechanical properties of FRP products available in the market is such a concern that it can ultimately change the performance of the strengthening. Also, investigation is needed to know more about the long-term durability of FRP materials especially when it comes to their performance under sustained loading and changing environmental conditions. Studies in the future can be oriented towards setting up standard protocols not just for FRP application but for the whole process, i.e., from optimal fiber orientation to appropriate layer thickness and to an application of the most effective bonding methods. Working on hybrids, combing CFRP and GFRP, is also one of the avenues that could lead to better performance, hence the need for further explorations here.

Furthermore, it is the case that large-scale field testing is a must to check the results obtained in the lab and to understand the real performance of the FRP-strengthened structures. To sum up, the review of literature and the experimental evidence have helped devise a scenario where the use of FRP increases the strength of RCC structures. The theoretical predictions matched closely with the experimental results indicating that the use of analytical models in the design of FRP components would be beneficial. Although FRP represents an economical and dependable reinforcing option, further studies have to be conducted to remove the barriers and to increase the understanding needed for safe and efficient use in practical engineering scenarios.

IV. Conclusion

The reinforcement of RCC beam-column joints with Fiber Reinforced Polymer (FRP) materials has been a major factor in turning up the overall performance of buildings and making them more resistant to seismic forces. FRP materials, in particular, are rapidly becoming the choice due to their excellent weight ratio, no corrosion, and easy application. The studies have testified that FRP strengthening can make the concrete component significantly higher in the load-carrying capacity, ductility, stiffness, and better in failure behavior, which makes it a very effective solution for the retrofitting of existing structures.

The reliability of such studies is further increased by the use of ANSYS software, which is capable of creating detailed structural models and making accurate predictions of the behavior of FRP-reinforced RCC systems under different loading conditions. The advanced simulation ability of ANSYS helps engineers in the areas of performance evaluation, safety assurance, and design strategy optimization.

In the future, research is going to look into new FRP types, better configurations, long-term durability aspects, and the establishment of universally accepted guidelines for the practical use of FRP. The validation of analytical and numerical models will be highly dependent on field applications and case studies. Nevertheless, the adoption of FRP in structural engineering practices is a promising sign of the safety, resilience, and longevity of the modern infrastructure.

References

[1] Natraj, K., Kirthiga, R., & Elavenil, S. (2023). Structural performance of RCC building and strengthening the structural members with CFRP. Materials Today: Proceedings, 84, 24-32.

[2] Tiwary, A. K., Singh, S., Chohan, J. S., Kumar, R., Sharma, S., Chattopadhyaya, S., ... & Stepinac, M. (2022). Behavior of RC beam– column joints strengthened with modified reinforcement techniques. Sustainability, 14(3), 1918.

[3] A., Suguna, I. D. K., & Ragunath, P. N. (2020). EXPERIMENTAL WITH FINITE ELEMENT ANALYSIS OF REINFORCED CONFINED CONCRETE WITH GFRP LAMINATES. Technology, 11(10), 951-968.

[4] Tejaswi, R., & George, G. (2023, June). Prediction of Shear Strength of Beam-Column Joint with Glass Fiber Reinforced Polymer Bars Using Response Surface Methodology. In International Conference on Structural Engineering and Construction Management (pp. 873-884). Cham: Springer Nature Switzerland.

[5] Dereje, L. S., Rynkovskaya, M. I., Dabi, G. M., Baza, T. T., Nagassa,E.K., & Mbuthia, N. D. (2023, November). The effect of joint deformations on the nonlinear behavior of retrofitted reinforced concrete structures. In AIP Conference Proceedings (Vol. 2936, No. 1). AIP Publishing.

[6] Rahgozar, N., &Rahgozar, N. (2024). Experimental and Numerical Investigation on Flexural Strengthening of Precast Concrete Corbel Connections with Fiber-Reinforced Plastic Sheet. Buildings, 14(2), 387.

[7] Simsek Turker, Y. (2024). Determination of cyclic behavior of various cross-section composite column-beam connections reinforced with FRP composite using FEM analysis and ML models. Wood Material Science &Engineering,1–14. https://doi.org/10.1080/17480272.2024.2407980.

[8] Zhou, Y., Wang, R., & Lu, Y. (2024). Seismic performance of confined prestressed hollow core wall panels part II: Numerical simulation and analysis. Journal of Building Engineering, 83, 108417.

[9] Kheyroddin, A., Raygan, S., &Kioumarsi, M. (2024). Strut and tie model for CFRP strengthened reinforced concrete corbels. Engineering Structures, 304, 117609.

[10] Rousakis, T., Anagnostou, E., &Fanaradelli, T. (2021). Advanced composite retrofit of RC columns and frames with prior damages— pseudodynamic finite element analyses and design approaches. Fibers, 9(9), 56.

[11] Kytinou VK, Kosmidou P-MK, Chalioris CE. Numerical Analysis Exterior RC Beam-Column Joints with CFRP Bars as Beam's Tensional Reinforcement under Cyclic Reversal Deformations. Applied Sciences. 2022;12(15):7419. https://doi.org/10.3390/app12157419