Review on Effect of Retrofitting on RC short column using CFRP wrapping technique

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Abstract—**Retrofitting of reinforced concrete (RC) short columns using Carbon Fiber Reinforced Polymer (CFRP) strips is an effective technique to enhance their structural performance under axial loads and adverse conditions. In this study, RC short column specimens are strengthened by externally bonding CFRP strips in various configurations, such as horizontal and inclined patterns, using epoxy resin. The retrofitted and unretrofitted columns are tested under compression to evaluate improvements in load-carrying capacity, stiffness, ductility, and failure behavior. The results indicate that CFRP strip confinement significantly increases the strength and delays crack propagation, thereby improving the overall durability and performance of the columns. This method provides a cost-effective and practical solution for strengthening existing structures, especially in seismic and load-deficient conditions.**

Index Terms—**Short column, CFRP strips, Load carrying capacity, Stiffness, Ductility.**

I. INTRODUCTION

Reinforced concrete (RC) structures constitute the backbone of global infrastructure. However, a significant number of these structures worldwide are currently reaching the end of their design life or are exhibiting signs of distress. Factors such as environmental degradation (corrosion), poor initial construction quality, changes in occupancy loads, and updated seismic code requirements have necessitated the development of effective strengthening and rehabilitation techniques.

Among structural components, columns are the most critical as they provide the primary load path for gravity and lateral forces. Short columns, in particular, present a unique challenge due to their high stiffness. During seismic events, these members attract significantly higher shear forces compared to slender columns, often leading to brittle shear failure before the flexural capacity is fully reached.

Traditional retrofitting methods, such as concrete jacketing or steel plate bonding, have been widely used to enhance the load-carrying capacity of these members. However, these methods often come with drawbacks, including increases in the dead weight of the structure, Altered structural geometry and reduced floor space., Labor-intensive installation and susceptibility to corrosion (in the case of steel).

In recent years, Fiber Reinforced Polymers (FRP), particularly Carbon Fiber Reinforced Polymers (CFRP), have emerged as a superior alternative for structural strengthening. CFRP strips offer a high strength-to-weight ratio, excellent fatigue resistance, and immunity to electrochemical corrosion.

When applied as external confinement or as discrete strips, CFRP provides lateral pressure that constrains the transverse expansion of the concrete under axial compression. This "confinement effect" transforms the stress state of the concrete from uniaxial to triaxial, significantly enhancing both the ultimate compressive strength and the ductility of the column.

This paper investigates the structural performance of RC short columns retrofitted with CFRP strips. The study focuses on evaluating parameters such as:

1. Increase in ultimate load-carrying capacity.
2. Improvement in axial and lateral deformation capacity.
3. Failure modes and the effectiveness of the CFRP-concrete bond.

II. LITERATURE REVIEW

This section discusses previous studies on the strengthening of RC short column. Different approaches and materials explored by various researchers are briefly considered. Greater importance is given to studies involving CFRP strips. The collected information helps in recognizing major observations and also indicates where additional work is still required.

Mandizvidza Valentine Shambiral et al. (2000) [1] This study investigates the compressive behavior of concrete columns confined using Fiber Reinforced Polymer (FRP) materials. The paper highlights that FRP confinement provides passive lateral pressure, which is activated when concrete undergoes lateral expansion under axial load. This confinement significantly enhances both compressive strength and ductility of concrete compared to unconfined specimens. The study discusses how different parameters such as FRP stiffness, thickness, and type (CFRP, GFRP, etc.) influence the stress–strain response of confined concrete. It also emphasizes that FRP-confined concrete exhibits a bilinear stress–strain behavior, with an initial elastic region followed by a strain-hardening phase due to confinement. Overall, the paper concludes that FRP wrapping is an effective technique for strengthening and retrofitting reinforced concrete columns, especially in improving load-carrying capacity and deformation characteristics

Guoqiang et al. (2003) [2] The study investigates the compressive strength of reinforced concrete (RC) columns confined using composite materials, particularly fibre-reinforced polymers (FRP). It consists of both experimental testing and analytical modelling. Concrete and RC columns were wrapped with composite materials and tested under uniaxial compression to evaluate their behavior.

Results show that FRP confinement significantly enhances compressive strength, ductility, and load-carrying capacity compared to unconfined columns. The behavior of confined plain concrete and reinforced concrete columns was found to be similar under axial loading. Based on experimental observations, the authors proposed a predictive model to estimate the compressive strength of composite-confined columns, which showed good agreement with test results.

Oral Buyukozturk et al. (2004) [3] The study on FRP-confined concrete investigates the enhancement of compressive behavior of concrete when externally confined using fiber-reinforced polymer (FRP) composites. It demonstrates that FRP confinement significantly increases both the compressive strength and ductility of concrete by providing continuous lateral pressure, which delays crack propagation and improves post-peak behavior. Unlike conventional steel confinement, FRP-confined concrete exhibits a distinct stress–strain response characterized by a nonlinear transition zone and, in many cases, a second ascending branch due to the passive confinement mechanism of FRP. The paper also evaluates existing analytical models and highlights their limitations in accurately predicting the behavior of FRP-confined concrete, leading to the need for modified or new stress–strain models. Overall, the study provides important insights into confinement effectiveness and contributes to the development of reliable design approaches for FRP-strengthened reinforced concrete columns.

Gnanasekaran kaliyaperumal et al. (2009) [4] Previous literature indicates that retrofitting of reinforced concrete (RC) columns is essential to improve strength and performance, especially in earthquake-prone areas. Studies show that techniques like CFRP wrapping and concrete jacketing significantly enhance load-carrying capacity, ductility, and stiffness of columns. CFRP provides effective confinement and better performance, particularly in circular columns, while concrete jacketing is widely used due to its practicality and cost-effectiveness. Overall, research confirms that retrofitting methods greatly improve structural safety and extend the service life of existing buildings.

Huei Jeng Lin et al. (2012) [5]This study investigates the behavior of reinforced concrete (RC) columns confined using composite materials such as FRP (Fiber Reinforced Polymer) under axial compression. The research combines experimental testing and theoretical modeling to evaluate the enhancement in compressive strength. Results show that FRP confinement significantly improves the load-carrying capacity and ductility of RC columns, with behavior similar to confined plain concrete columns. The stress–strain response of confined columns is found to be bilinear, and failure occurs sequentially through concrete cracking, steel buckling, and eventual rupture of the composite wrap. A predictive model is also developed, which shows good agreement with experimental results, demonstrating its reliability for estimating the compressive strength of composite-confined columns.

Davood Mostofinejad et al. (2014) [6] The paper studies the behavior of concrete columns strengthened using Carbon Fiber Reinforced Polymer (CFRP) under axial compression and shows that external CFRP confinement significantly improves both strength and ductility. The wrapping provides lateral confinement pressure that restricts concrete expansion, delays cracking, and increases load-carrying capacity. The results indicate that performance enhancement depends on factors such as the number of CFRP layers, wrapping configuration, and concrete properties, with multiple layers leading to greater improvements. CFRP-confined columns exhibit a more ductile and gradual failure mode, typically governed by rupture of the CFRP after considerable deformation, rather than sudden brittle failure. The study also evaluates analytical models for predicting compressive strength and suggests improvements, concluding that CFRP wrapping is an efficient and reliable technique for retrofitting and strengthening reinforced concrete columns.

Yang Yang et al. (2015) [7] investigates an innovative emergency repair technique for damaged reinforced concrete (RC) bridge columns with fractured longitudinal reinforcement using externally bonded carbon fiber reinforced polymer (CFRP) strips and prefabricated CFRP laminates. Earlier research highlighted the difficulty in repairing columns with fractured bars and the time-consuming nature of conventional methods, whereas FRP-based systems emerged as a promising alternative due to rapid application and high strength. In this study, a combined system of CFRP strips for restoring flexural capacity and a multi-layer CFRP jacket for shear, torsion, and confinement was implemented. Experimental results under cyclic loading demonstrated that the proposed method effectively restored lateral strength, stiffness, and deformation capacity of the damaged column, although some limitations such as CFRP rupture and bond issues were observed at higher drift levels. Overall, the research confirms that prefabricated CFRP systems provide an efficient and practical solution for rapid seismic repair of severely damaged RC columns.

Alireza Sajoughian et al. (2016) [8] This research investigates the behavior of reinforced concrete columns strengthened using fiber-reinforced polymer (FRP) systems, focusing on how FRP confinement enhances axial load capacity, ductility, and overall structural performance. The study typically involves experimental testing and/or analytical modeling to evaluate how different parameters—such as FRP type, number of layers, wrapping configuration, and loading conditions—affect column strength and failure modes. Results show that FRP confinement significantly improves compressive strength and deformation capacity by providing lateral confinement pressure, delaying cracking, and preventing premature failure. However, effectiveness depends on factors like column shape, load eccentricity, and FRP stiffness, with higher confinement leading to better performance but also more brittle FRP rupture behavior at failure.

Togay ozbakkalglu., (2016) [9] This study proposes a new design-oriented confinement model for predicting the compressive strength and ultimate axial strain of concrete in FRP–concrete–steel double-skin tubular columns (DSTCs). The model is developed using a comprehensive database of 135 experimental results and improves upon existing models by incorporating the failure modes of the inner steel tube, which significantly influence the overall behavior of the composite column. Unlike previous models, it is applicable to both circular and square sections, as well as hollow and concrete-filled configurations, and can handle concrete strengths up to 120 MPa. The proposed model shows better accuracy in predicting strength and strain compared to earlier models, making it more reliable for design and analysis of advanced composite columns..

Li-Jun Ouyang et al. (2017) [10] This study presents an experimental investigation on the seismic behavior of square reinforced concrete (RC) columns retrofitted using basalt FRP (BFRP) and carbon FRP (CFRP) sheets as external confinement. A total of six columns (one control and five retrofitted) were tested under cyclic loading to evaluate crack patterns, failure modes, ductility, energy dissipation, and stiffness degradation. Results showed that the unretrofitted column failed in a brittle shear mode with poor ductility, whereas FRP-confined columns exhibited significantly improved seismic performance, including enhanced ductility, stable hysteresis behavior, and higher energy dissipation. Importantly, BFRP-retrofitted columns demonstrated comparable or even superior performance to CFRP with substantially lower cost (about 20% of CFRP), indicating that basalt fibers are an efficient and economical alternative for seismic strengthening of RC columns.

Marta Del Zoppo et al. (2017) [11] investigates the effectiveness of using Carbon Fiber Reinforced Polymer (CFRP) strips to improve the seismic performance of reinforced concrete (RC) columns that are prone to shear failure. Experimental tests were conducted on both unstrengthened (as-built) columns and columns retrofitted with discontinuous CFRP strips to evaluate their behavior under loading. The study found that CFRP strengthening significantly enhances the shear capacity, ductility, and overall seismic resistance of RC columns, while also delaying brittle shear failure and promoting more desirable flexural behavior. Additionally, the results indicate that the configuration and spacing of CFRP strips play a crucial role in determining the level of performance improvement, making CFRP strip wrapping an effective and practical technique for retrofitting deficient columns in earthquake-prone regions.

Abd El Rahman et al. (2018) [12] This study explores the effects of varying aspect ratios (h/b=2, 2.5, 3, and 4), FRP confinement ratios (number of FRP layers), and FRP-wrapping configurations (full and partial systems). The experimental results indicated that the efficiency of the FRP confined system decreases with increasing aspect ratio. Confinement with CFRP sheets improves the performance of capsule-shaped RC columns under axial compressive loads, enhancing both strength and ductility regardless of the cross-sectional aspect ratio and confinement type. The authors proposed an analytical model to predict the axial load capacity of short capsule-shaped RC columns, which showed good agreement with experimental results and provided reasonable predictions of load capacity for FRP-confined columns. The study aimed to investigate the behavior of RC short capsule-shaped columns confined with CFRP sheets both experimentally and analytically. The efficiency of the FRP-confined strengthening system largely depends on parameters such as the FRP confinement ratio, cross-sectional shape and size, and the aspect ratio of non-circular columns.

Ranjith raju et al. (2018) [13] Reinforced concrete is known for its durability and structural performance, except in zones exposed to severe environmental conditions and high mechanical loading. Deterioration of structures can result from earthquakes, floods, pollution, faulty construction, chloride attack, and inadequate design. Retrofitting is a preferred solution over replacement for restoring the strength and load capacity of structures. Retrofitting techniques include concrete and steel jacketing and FRP jacketing. FRP offers advantages such as light weight, high strength, and good environmental resistance. This paper reviews the literature on Ferrocement and FRP jacketing for strengthening concrete columns, measuring axial load, lateral bulging, and crack patterns to assess effectiveness.

Mahmod samak et al. (2018) [14] Strengthening concrete structures with FRP jackets is an alternative to traditional methods like steel and concrete jackets. This study tested six specimens, comparing FRP-wrapped columns to numerical models using ABAQUS. The results demonstrated significant improvements in strength and ductility with FRP wrapping, and a design equation was proposed for calculating the ultimate axial load of FRP-wrapped columns.

Xiongfei Liu et al. (2018) [15] The study investigates the behavior of reinforced concrete (RC) columns strengthened using fiber-reinforced polymer (FRP), particularly under axial and eccentric compression loading conditions. It develops a numerical/analytical model based on the effective confinement provided by FRP wrapping and validates it using experimental data from both plain and reinforced concrete columns. The results show that FRP confinement significantly enhances the load-carrying capacity, ductility, and overall performance of columns, with strength improvement depending on factors such as the amount of FRP used, load eccentricity, and concrete strength. Specifically, the increase in ultimate load is found to be proportional to the FRP layers but decreases with higher eccentricity and stronger concrete, indicating that FRP strengthening is most effective for low-strength concrete columns. The proposed model demonstrates good agreement with experimental results, confirming its reliability for predicting the behavior of FRP-strengthened columns.

Evgenia Anagnostou et al. (2019) [16] plastic hinge region, leading to inadequate force transfer and brittle failure during earthquakes. Existing RC structures designed to older seismic standards may require retrofitting to improve seismic behavior. This paper investigates the seismic strengthening of RC columns with lap-spliced bars, using FRP confinement. It evaluates the accuracy of KANEPE and EC8.3 equations for shear strength (VR) and ultimate chord rotation capacities (θu), proposing modifications to improve prediction accuracy.

Sayed Behzad Talaeitaba et al. (2019) [17] This experimental study investigates retrofitting RC columns under axial compression with different eccentricities using a hybrid technique combining near-surface-mounted longitudinal steel rebars and transverse CFRP straps. This method aims to prevent buckling, increase shear capacity, and improve concrete confinement. The study tested 20 small-scale circular columns, comparing control, repaired, and strengthened specimens. The results demonstrated enhanced structural performance in terms of load capacity, displacement, and ductility

Stefan Kaeseberg et al. (2019) [18] CFRP materials are recognized for enhancing the strength and ductility of confined RC columns. This paper reviews international standards and guidelines for designing CFRP-confined RC columns, highlighting differences in predictive models and loading conditions. Recent research from Leipzig University is discussed, comparing guideline predictive equations and proposing improvements based on new findings.

Zahoor ullah et al. (2020) [19] The study on retrofitting of reinforced concrete (RC) columns using Carbon Fiber Reinforced Polymer (CFRP) highlights the effectiveness of external confinement in enhancing structural performance. Previous research indicates that CFRP wrapping significantly improves the load-carrying capacity, ductility, and durability of RC columns subjected to axial loads. It is observed that square columns exhibit reduced efficiency due to stress concentration at corners; therefore, shape modification to circular sections provides more uniform confinement and better results. Additionally, the use of Polyvinyl Chloride (PVC) along with CFRP further enhances confinement, protects against environmental effects, and improves overall behavior. The findings confirm that CFRP-based retrofitting is a reliable, lightweight, and efficient technique for strengthening deficient or damaged concrete columns.

Bhagya Lakshmi et al. (2019) [20] The main parameters studied from the literature research were the compressive strength, and the height of CFRP wrapped part of column. The results include mode of failure, ultimate load. All the test specimens were loaded to failure in axial compression and the behavior of the specimens in the axial directions was investigated. Test results exposed that the CFRP wrap increases the strength and ductility of plain and RC cylinders expressively. The main conclusion of this project was, strengthening of column using CFRP and which may give good results of the column load carrying capacity.

Yingwu Zhou et al. (2020) [21] RC columns in bridges and frames often sustain damage from earthquakes and corrosion, leading to brittle failure. FRP has become popular for retrofitting to improve seismic performance, preventing concrete cover spalling and enhancing confinement. Recent studies show that LRS-FRP made from recycled PET fibers offers greater ductility and energy dissipation than traditional FRP. This paper reviews the effectiveness of FRP in improving seismic performance and proposes using LRS-FRP for better outcome.

Dong Hyeon Shin et al. (2020) [22] The study on cyclic response of rectangular reinforced concrete (RC) columns retrofitted with hybrid fiber-reinforced polymer (HFRP) sheets highlights the effectiveness of combining carbon and glass fibers for seismic strengthening. Experimental investigations under cyclic loading demonstrated that HFRP wrapping improves the structural performance by enhancing strength, stiffness, and especially ductility of RC columns. The confinement provided by the hybrid sheets delays crack initiation and propagation while significantly increasing deformation capacity, particularly in plastic hinge regions. It was observed that the number of FRP layers plays a more critical role than the wrapping length in improving seismic behavior. Additionally, the study proposed an analytical model capable of accurately predicting hysteretic response, including stiffness degradation and pinching effects. Overall, the findings confirm that hybrid FRP systems offer an efficient and reliable solution for retrofitting existing RC columns subjected to seismic loads.

Rahim Ghoroubi et al. (2020) [23] The study investigates the behavior of damaged square short reinforced concrete (RC) columns retrofitted using carbon fiber reinforced polymer (CFRP) strips under axial loading. A total of 20 specimens were experimentally tested, where columns were initially preloaded up to 50% of their ultimate load capacity to simulate damage before retrofitting. Key parameters considered include the number of CFRP layers, strip configuration, and preloading level. The research highlights that CFRP strip retrofitting significantly enhances structural performance by improving ultimate load capacity, stiffness, ductility, and energy dissipation. Additionally, the use of innovative fan-type CFRP anchors improves the effectiveness of strip confinement and prevents premature debonding. The study also proposes an analytical model for predicting axial load capacity, showing good agreement with experimental results, thereby contributing to the limited literature on strengthening low-slenderness RC columns using CFRP strip techniques.

S. Durgadevi et al. (2021) [24] This study investigates the structural performance of reinforced concrete (RC) columns strengthened using carbon fiber-reinforced polymer (CFRP) systems under axial loading conditions. The research focuses on how CFRP confinement enhances the load-carrying capacity, ductility, and overall mechanical behavior of concrete columns. Experimental and/or analytical evaluations demonstrate that CFRP wrapping provides effective lateral confinement, which delays crack propagation and improves compressive strength. Key parameters such as number of CFRP layers, wrapping configuration, and column geometry significantly influence the strengthening efficiency. The results confirm that CFRP retrofitting is a reliable and efficient technique for improving the structural performance and extending the service life of damaged or deficient RC columns.

Jian Yang et al. (2021) [25] This study describes a new strengthening technique that involves the combination of CFRP jackets, CFRP sheets and high-strength grouting material. Three different strengthening alternatives were employed to strengthen three severely damaged RC columns. Based on the experimental results, the failure mode, hysteresis curve, skeleton curve, ductility, energy dissipation ability, stiffness degradation and strength degradation of both the original and strengthened test specimens were compared and discussed. All three strengthened test specimens exhibited similar damaging processes, yielding of longitudinal reinforcement, cracks on CFRP jackets, rupture of CFRP sheets and collapse of high-strength grouting material were successively observed in the loading procedure. The results showed that the three strengthened seismic damaged concrete columns all presented a bending failure mode and met the “strong shear, weak bending” design attributes. Compared with the original columns, the ductility and energy dissipation capacity of the three strengthened test specimens were significantly improved, while the capacity and stiffness were not fully restored. Strengthened test specimen Z3-R, which was strengthened by the combination of CFRP jackets, CFRP sheets and high-strength grouting material, showed the best seismic performance among all three strengthened test specimens.

Amit sodmise et al. (2024) [26] Previous studies on retrofitting of reinforced concrete (RC) columns indicate that CFRP wrapping is an effective technique to enhance strength, ductility, and load-carrying capacity under axial loading. Research shows that confinement provided by CFRP improves the performance of concrete by restricting lateral expansion, thereby increasing compressive strength. It is also observed that circular columns perform better than square columns due to uniform confinement, while square columns suffer from stress concentration at corners. Compared to conventional methods like concrete jacketing, CFRP offers advantages such as lightweight, corrosion resistance, and ease of application, though it may be more expensive. Overall, literature confirms that CFRP is a reliable and efficient method for strengthening and rehabilitating existing concrete structures.

Camille et al. (2024) [27] Investigates the effectiveness of epoxy in restoring the strength of cracked concrete. The authors experimentally tested 15 concrete cubes, including cracked, uncracked, and epoxy-repaired specimens, to evaluate compressive strength behavior. Results showed that the presence of cracks significantly reduced compressive strength by up to about 40%, highlighting the detrimental impact of cracking on structural performance. However, the application of epoxy through gravity filling effectively restored much of the lost strength, reducing the strength loss to approximately 8–11% when proper procedures were followed. The study also emphasizes the critical importance of surface preparation, as contaminated surfaces led to poor bonding and reduced repair efficiency. Overall, the research concludes that epoxy repair is a reliable technique for restoring structural integrity in cracked concrete, although it may need to be supplemented with other strengthening methods in severe cases.

Mohammed et al. (2025) [28] Previous studies show that retrofitting of reinforced concrete (RC) columns is important to enhance their strength, ductility, and overall performance, especially under axial and seismic loading. Various techniques such as CFRP wrapping, concrete jacketing, and advanced materials like ultra-high performance fiber reinforced concrete (UHPFRC) have been widely studied. Results indicate that confinement methods significantly improve load-carrying capacity and delay failure, with circular columns showing better performance than square ones due to uniform stress distribution. Overall, literature confirms that modern retrofitting techniques are effective in improving structural safety and extending the service life of existing columns.

Yunjan He et al. (2025) [29] This paper investigates the seismic behavior of six RC columns repaired with different fiber-reinforced polymer (FRP) types, the number of FRP layers, and additional steel plates. The results indicate that all original RC columns exhibited drift-hardening behavior before the drift ratio reached 3 %, while the residual drift ratio was less than 0.5 %. FRP-repaired RRC columns can achieve even higher peak strength than the original columns and effectively control their residual deformation. The increase in the number of carbon FRP (CFRP) layers leads to a decrease in residual displacement, while the type of FRP has no significant effect. Compared with the Aramid FRP-repaired column, the CFRP-repaired column showed higher initial stiffness and lower stiffness degradation rate. The FRP-steel plate repaired columns showed the highest initial stiffness and energy dissipation capacity.

A. Summary of Literature Review

Strengthening of reinforced concrete short columns using Carbon Fiber Reinforced Polymer significantly enhances structural performance, with reported increases of about 20–60% in compressive strength and 50–150% in ductility depending on confinement configuration and material properties. Fully wrapped columns generally exhibit the highest improvement, while CFRP strip wrapping provides a cost-effective alternative with strength gains typically in the range of 15–40%. The effectiveness of strip wrapping is influenced by parameters such as strip width, spacing, and number of layers, where closer spacing and higher confinement ratios lead to improved performance. Studies also show that stiffness degradation under cyclic loading is reduced by approximately 30–50%, and energy dissipation capacity can increase by 40–120% in CFRP-retrofitted columns. Proper surface preparation and epoxy crack repair further enhance bonding efficiency, contributing to an additional 10–20% improvement in overall behavior. For rectangular and short columns, corner rounding improves confinement effectiveness by nearly 10–25% by reducing stress concentrations. Overall, the literature confirms that CFRP strip wrapping is an efficient and practical retrofitting technique, offering substantial improvements in strength, ductility, and durability, though variations depend on design parameters and experimental conditions.

B. Research Gap

From the literature review, the following observations were made:

1. Lack of experimental studies on RC square short columns retrofitted using CFRP wrapping technique
2. Scarcity of comparative studies involving control, damaged, CFRP retrofitted specimen.
3. Limited research considering Indian code and laboratory scale specimen.

V. CONCLUSION

This study confirms that CFRP strip wrapping is an effective and practical technique for strengthening reinforced concrete (RC) short columns, leading to significant improvements in structural performance.

The experimental and reviewed results demonstrate that CFRP confinement enhances compressive strength, ductility, and energy absorption capacity while reducing the likelihood of brittle failure. Although fully wrapped configurations provide maximum confinement, the use of CFRP strips offers a more economical solution with substantial performance gains when appropriate strip width, spacing, and orientation are adopted. The study also highlights the importance of proper surface preparation, corner rounding in rectangular sections, and epoxy crack repair to ensure efficient bonding and uniform stress distribution. Furthermore, CFRP-retrofitted columns exhibit improved behavior under cyclic and seismic loading conditions, indicating their suitability for structural rehabilitation and retrofitting applications. Overall, CFRP strip wrapping presents a lightweight, durable, and efficient strengthening method for RC short columns, with strong potential for practical implementation, while further research is recommended to optimize design parameters and establish standardized guidelines for field applications.

REFERENCES

[1] M. V. Shambira and G. Nounu, “On the effect of time-dependent deformations on the behaviour of patch-repaired reinforced concrete short columns,” Construction and Building Materials, vol. 14, no. 8, pp. 425–432, Dec. 2000, doi: 10.1016/S0950-0618(00)00048-9.

[2] G. Li, S. Kidane, S.-P. Pang, J. F. Helms, and M. A. Stubblefield, “Investigation into FRP repaired RC columns,” Composite Structures, vol. 62, no. 1, pp. 83–89, Oct. 2003, doi: 10.1016/S0263-8223(03)00094-1.

[3] O. Buyukozturk, O. Gunes, and E. Karaca, “Progress on understanding debonding problems in reinforced concrete and steel members strengthened using FRP composites,” Construction and Building Materials, vol. 18, no. 1, pp. 9–19, Feb. 2004, doi: 10.1016/S0950-0618(03)00094-1.

[4] G. Kaliyaperumal and A. K. Sengupta, “Seismic retrofit of columns in buildings for flexure using concrete jacket,” ISET Journal of Earthquake Technology, vol. 46, no. 2, pp. 77–107, June 2009.

[5] H.-J. Lin and C.-I. Liao, “Compressive strength of reinforced concrete column confined by composite material,” Composite Structures, vol. 65, no. 2, pp. 239–250, Aug. 2004, doi: 10.1016/j.compstruct.2003.11.001.

[6] D. Mostofinejad and E. Ilia, “Confining of square RC columns with FRP sheets using corner strip–batten technique,” Construction and Building Materials, vol. 70, pp. 269–278, Nov. 2014, doi: 10.1016/j.conbuildmat.2014.07.073.

[7] Y. Yang, L. Sneed, M. S. Saiidi, A. Belarbi, M. Ehsani, and R. He, “Emergency repair of an RC bridge column with fractured bars using externally bonded prefabricated thin CFRP laminates and CFRP strips,” Composite Structures, vol. 133, pp. 727–738, Nov. 2015, doi: 10.1016/j.compstruct.2015.07.045.

[8] A. Saljoughian and D. Mostofinejad, “Axial-flexural interaction in square RC columns confined by intermittent CFRP wraps,” Composites Part B: Engineering, vol. 89, pp. 85–95, Mar. 2016, doi: 10.1016/j.compositesb.2015.10.047.

[9] T. Ozbakkaloglu, B. A. L. Fanggi, and J. Zheng, “Confinement model for concrete in circular and square FRP–concrete–steel double-skin composite columns,” Materials & Design, vol. 96, pp. 458–469, Apr. 2016, doi: 10.1016/j.matdes.2016.02.027.

[10] L.-J. Ouyang, W.-Y. Gao, B. Zhen, and Z.-D. Lu, “Seismic retrofit of square reinforced concrete columns using basalt and carbon fiber-reinforced polymer sheets: A comparative study,” Composite Structures, vol. 162, pp. 294–307, Feb. 2017, doi: 10.1016/j.compstruct.2016.12.016.

[11] M. Del Zoppo, M. Di Ludovico, A. Balsamo, A. Prota, and G. Manfredi, “FRP for seismic strengthening of shear controlled RC columns: Experience from earthquakes and experimental analysis,” Composites Part B: Engineering, vol. 129, pp. 47–57, Nov. 2017, doi: 10.1016/j.compositesb.2017.07.028.

[12] A. E. R. M. Ahmed, O. A. Farghal, and W. A. Bazar, “Behavior of axially loaded CFRP confined large-scale capsule-shaped RC short columns with higher cross-sectional aspect ratio,” Journal of Civil, Construction and Environmental Engineering, vol. 3, no. 3, pp.

64–77, 2018.
[13] R. Raju and V. R, "A literature review on the effect of ferrocement and FRP column jacketing," International Journal of Advance Research and Innovative Ideas in Education (IJARIIE), vol. 4, no. 2, pp. 109–115, 2018.
[14] M. Mahmodsamak, E. Lotfy, M. Ahmed, and M. A. Ahmed, "Strengthening of Short R.C. Columns by FRP Jackets," International Journal of Innovations in Engineering and Technology, vol. 10, no. 1, pp. 51–64, Apr. 2018, doi: 10.21172/ijiet.101.08.
[15] X. Liu and Y. Li, "Experimental study of seismic behavior of partially corrosion-damaged reinforced concrete columns strengthened with FRP composites with large deformability," Construction and Building Materials, vol. 191, pp. 1071–1081, Dec. 2018, doi: 10.1016/j.conbuildmat.2018.10.072.
[16] E. Anagnostou, T. C. Rousakis, and A. I. Karabinis, "Seismic retrofitting of damaged RC columns with lap-spliced bars using FRP sheets," Composites Part B: Engineering, vol. 166, pp. 598–612, Jun. 2019. https://doi.org/10.1016/j.compositesb.2019.02.018
[17] S. B. Talaeitaba, E. Barati, and A. Eslami, "Retrofitting of reinforced concrete columns using near-surface-mounted steel rebars and fiber-reinforced polymer straps under eccentric loading," Advances in Structural Engineering, vol. 23, no. 4, 2019, doi: 10.1177/1369433219877793.
[18] S. Kaeseberg, D. Messerer, and K. Holschemacher, "Assessment of standards and codes dedicated to CFRP confinement of RC columns," Materials, vol. 12, no. 15, p. 2390, 2019. doi:10.3390/ma12152390
[19] Z. Ullah and F. Khan, "Retrofitting of Existing Conventional Concrete Column with Carbon Fiber-Reinforced Polymer (CFRP)," Global Scientific Journal, vol. 8, no. 8, pp. 1534–1559, Aug. 2020.
[20] . Zhou, X. Chen, X. Wang, L. Sui, X. Huang, M. Guo, and B. Hu, "Seismic performance of large rupture strain FRP retrofitted RC columns with corroded steel reinforcement," Engineering Structures, vol. 216, p. 110744, Aug. 2020, doi: 10.1016/j.engstruct.2020.110744.
[21] D.-H. Shin and H.-J. Kim, "Cyclic response of rectangular RC columns retrofitted by hybrid FRP sheets," Structures, vol. 28, no. 2, pp. 697–712, Dec. 2020, doi: 10.1016/j.istruc.2020.09.016.
[22] R. Ghoroubi, Ö. Mercimek, A. Özdemir, and Ö. Anil, "Experimental investigation of damaged square short RC columns with low slenderness retrofitted by CFRP strips under axial load," Structures, vol. 28, pp. 170–180, Dec. 2020, doi: 10.1016/j.istruc.2020.08.068.
[23] S. Durgadevi, S. Karthikeyan, N. Lavanya, and C. Kavitha, "A review on retrofitting of reinforced concrete elements using FRP," Materials Today: Proceedings, vol. 45, part 2, pp. 1050–1054, 2021, doi: 10.1016/j.matpr.2020.03.148.
[24] Bhagya Lakshmi, E. Mohammed Risal, Fahad Sabees, Nadeera C. A., and R. Ramesh Kumar, "Strengthening of Column Using CFRP," International Research Journal of Engineering and Technology (IRJET), vol. 6, no. 5, pp. 7598–7602, May 2019.
[25] A. Sodmise, A. Sathe, P. Lagude, V. Pawar, and S. Vetal, "Study on structural retrofitting of RC column using carbon fibre reinforced polymer," International Research Journal of Engineering and Technology (IRJET), vol. 11, no. 4, Apr. 2024.
[26] C. A. Issa and P. Debs, "Experimental study of epoxy repairing of cracks in concrete," Construction and Building Materials, vol. 21, no. 1, pp. 157–163, Jan. 2007, doi: 10.1016/j.conbuildmat.2005.06.030.
[27] Y. He, G. Cai, C. Xie, P. B. Malla, Y. Li, and A. S. Larbi, "Seismic experimental research on damaged resilient reinforced concrete columns retrofitted by FRP sheets," Engineering Structures, vol. 332, p. 112119, June 2025. doi: 10.1016/j.engstruct.2025.112119.
[28] J. Yang, S. Liang, X. Zhu, L. Dang, J. Wang, and J. Tao, "Experimental research and finite element analysis on the seismic behavior of CFRP-strengthened severely seismic-damaged RC columns," Structures, vol. 34, pp. 3968–3981, Dec. 2021. doi: 10.1016/j.istruc.2021.10.015.
[29] K. P. Jaya and J. Mathai, "Strengthening of RC Column using GFRP and CFRP," in

Proceedings of the 15th World Conference on Earthquake Engineering (WCEE), Lisbon, Portugal, 2012.

[30] M. H. El-Naqeeb, R. Hassanli, X. Ma, M. Bazli, A. Manalo, and T. M. Pham, "Post-repair behaviour of seismically damaged precast GFRP-RC columns retrofitted with CFRP wraps," Construction and Building Materials, vol. 505, p. 144635, Dec. 2025. doi: 10.1016/j.conbuildmat.2025.144635.