International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Carbon Fibre Reinforced Polymer (CFRP) In Bridge Strengthing

Sreya Ks* , Aswathy S**, Akash B **

**B.Tech student ,Department of Civil Engineering , Ahalia school of Engineering and Technology, Palakkad 678557*
*** B.Tech student ,Department of Civil Engineering , Ahalia school of Engineering and Technology, Palakkad 678557*
**** B.Tech student ,Department of Civil Engineering , Ahalia school of Engineering and Technology, Palakkad 678557*

A B S T R A C T

—Bridge strengthening is now urgently needed everywhere because of deteriorating environmental conditions, growing traffic volumes, and ageing infrastructure. Carbon Fiber Reinforced Polymer (CFRP) composites have become a dependable substitute for traditional bridge repair techniques. The remarkable tensile strength, low weight, and corrosion resistance of these materials render them ideal for prolonging the lifespan of metallic and reinforced concrete (RC) bridges. The latest developments in CFRP-based bridge strengthening methods, such as mechanical anchorage solutions, prestressed applications, and externally bonded systems, are compiled in this review paper. In addition to highlighting case studies and monitoring techniques, the benefits, drawbacks, and potential future developments are also discussed.

Keywords: CFRP, bridge strengthening, prestressing, anchorage, retrofitting, durability

1. INTODUCTION

The foundation of current transport networks is made up of bridges. However, heavy traffic, environmental deterioration, and material ageing are putting an increasing amount of stress on many older structures. Because replacing these bridges is costly and disruptive, strengthening solutions are crucial.

Over the past few decades, carbon fiber reinforced polymer (CFRP) composites have emerged as one of the most promising strengthening materials. CFRP has been effectively used for both RC and metallic bridges because of its high strength-to-weight ratio, exceptional longevity, and ease of application. The invention, uses, and effectiveness of CFRP in bridge strengthening are reviewed in this research.

2. WHY BRIDGES REQUIRE STRENGTHENING

There are several factors that contribute to bridge deterioration:

- Traffic demands that surpass the initial design capacity
- Corrosion of steel reinforcement
- Environmental deterioration, including carbonation and freeze-thaw cycles
- Aging of construction materials
- Random mistakes in the design or details

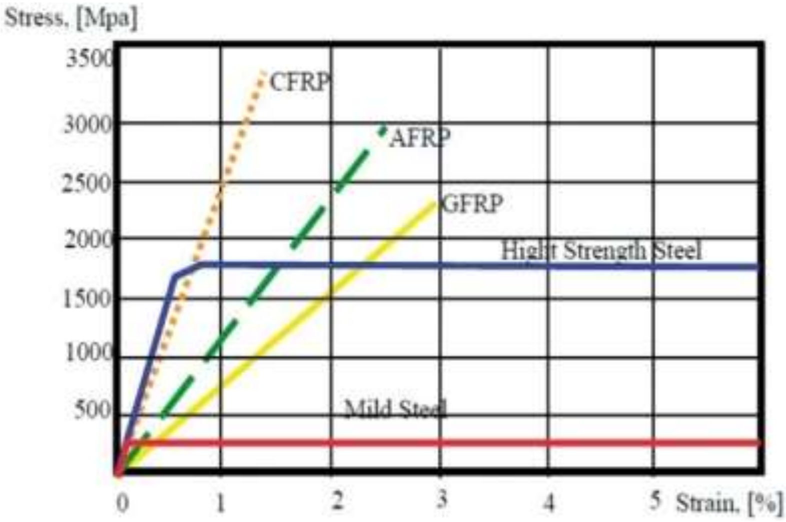
In these situations, CFRP offers a less invasive method of strengthening and prolonging service life without having to replace the structure [5]

3. BEHAVIOUR OF FRPS AND STEEL UNDER STRESS AND STRAIN

The graph demonstrates the stress-strain properties of mild steel and high-strength steel with Fiber Reinforced Polymer (FRP) composites, such as GFRP (glass), AFRP (aramid), and CFRP (carbon).

- Carbon fiber reinforced polymer (CFRP)
    - The highest tensile strength (up to about 3500 MPa) is displayed.
    - It displays a very high stiffness (modulus of elasticity) and is straight and steep.
    - Failure comes abruptly, brittle, and without compromise.

- Aramid Fiber Reinforced Polymer(AFRP)
  - Has a somewhat rigid structure and a high strength (~2500 MPa).
  - Behaves in a linearly elastic manner till failure.
- Glass fiber reinforced polymer (GFRP)
  - Tensile strength is lower (~2000 MPa) than CFRP and AFRP.
  - Although it is more ductile than CFRP, it still breaks easily.
- Super strength steel
  - ~1800 MPa tensile strength, which is significant but less than CFRP
  - Demonstrates yielding and strain hardening, which gives it ductility prior to failure.
- Mild steel
  - least strong (around 250 MPa),but ductility is really high
  - Under overloads, the flat plates suggests a significant deformation capacity, which makes it more forgiving



Key Insights from the Graph:

Steel and FRPs: Steel exhibits ductility and a yield point, but FRPs (CFRP, AFRP, and GFRP) exhibit linear elastic behavior up to failure with no yielding. Strength versus Ductility Trade-off: Steel has greater ductility but less strength, while CFRP offers very high strength but brittle failure. Material Selection: Steel is still preferred in applications requiring ductility and energy absorption, whereas CFRP is best suited for strengthening applications where high tensile strength and corrosion resistance are crucial.

4. PROPERTIES OF CFRP MATERIALS

The two primary parts of CFRP are carbon fibbers, which give it tensile strength, and a polymer matrix, typically epoxy, which holds the fibers together and shields them from harm. CFRP weighs a fraction of what steel does, yet it is two to five times stronger in stress [3], [4]. When it comes to bridge retrofitting, when adding mass is undesirable, CFRP is especially appealing because of these qualities.

5. CFRP STRENGTHENING TECHNIQUES

5.1 Bonded Systems

To improve the flexural and shear capacity, CFRP sheets or plates have been employed extensively for externally bonded reinforcement (EBR). These techniques offer quick increase in strength and stiffness and are comparatively simple to implement on-site [6], [7].

5.2 Prestressed Systems

Prestressing CFRP strips or bars allow engineers to take advantage of the material's high tensile strength. In both lab and field tests, prestressed bonded plates and near-surface-mounted (NSM) bars have demonstrated outstanding performance [8], [9].

5.3 Mechanical Anchorage Systems and Unbonded Systems

Mechanical clamping-based unbonded systems have been created to solve debonding and durability problems. These techniques have shown excellent performance in metallic bridges, even under fatigue stress, and do not require the use of adhesives [10], [11].

6. ANCHORAGE AND DURABILITY

In CFRP strengthening, the anchorage system is frequently the weakest aspect. Over time, environmental damage or creep may cause adhesive-based anchors to lose their effectiveness. Research shows that gradient anchorages and mechanical clamps perform better in the long run, although installation is more complex [12]–[14].

7. PERFORMANCE MONITORING

Monitoring is essential for assessing long-term efficacy because CFRP applications are still in their early stages. A number of methods have been successful:

Over several years of use, prestress levels in CFRP strips can be monitored using wireless sensor networks [10].

Fiber Bragg grating (FBG) sensors provide distributed strain data, making it possible to assess the global stiffness of strengthened bridges [15]. Performance under actual traffic conditions can be assessed with the aid of dynamic load monitoring [16].

8. CASE STUDIES

- **Torretta Bridge, Italy**: CFRP extended service life with little disturbance by restoring structural integrity to a deteriorated deck.
- **Zaha Hadid Bridge, Saudi Arabia**: CFRP was utilised in account of its lightweight nature, which allowed for the accomplishment of both structural and aesthetic objectives.
- **122-Year-Old Metallic Bridge, Australia**: Prestressed CFRP plates reduced girder stresses in half, and long-term stability was confirmed by monitoring [10].

9. ADVANTAGES AND LIMITATIONS

Advantages:	Limitations:
Enhanced stiffness and tensile strength	high initial cost when compared to conventional materials
remarkably light, offering speedy installation	reliance on trustworthy anchoring mechanisms
Resistance to corrosion and fatigue	Uncertainties regarding endurance in severe environments
extended lifespan and less maintenance	

10. FUTURE OUTLOOK

The potential of CFRP is being further explored by ongoing research in a number of ways:

- Real-time monitoring using smart CFRP composites with integrated sensors
- Self-healing resins to automatically repair micro cracks
- Carbon and additional fibers are combined in hybrid composites to enhance performance.
- standardised recommendations to promote more worldwide usage [17]–[20]

11. CONCLUSION

From an experimental material, CFRP has developed into a workable and widely used alternative for bridge reinforcement. It enables engineers to effectively and minimally disturb structures in order to prolong their lifespan. Although problems like cost and anchorage durability still exist, developments in material science, monitoring, and prestressing suggest that CFRP will eventually be used as a conventional solution in bridge engineering.

Acknowledgements

The authors would like to sincerely thank Ms. Krishnapriya S., Assistant Professor in the Department of Civil Engineering, for her help and direction during this effort.

References

[1] T. Siwowski, B. Piątek, P. Siwowska, and A. Wiater, "Development and implementation of CFRP post-tensioning system for bridge strengthening," *Engineering Structures*, vol. 207, p. 110266, 2020.

[2] Y. Almomani, N. Yazdani, and E. Beneberu, "In situ evaluation of CFRP strengthening for corrosion-deteriorated bridge bent caps," *J. Bridge Eng.*, vol. 25, no. 5, p. 04020019, 2020.

[3] B. Wu, Q. Xia, Y. Gong, S. Fu, H. Wang, and Z. Guo, "Evaluation of the strengthening effects on prestressed CFRP-strengthened steel beam bridges using macro-strain influence lines," *Buildings*, vol. 14, p. 2535, 2024.

[4] E. Ghafoori, A. Hosseini, R. Al-Mahaidi, X. Zhao, and M. Motavalli, "Prestressed CFRP-strengthening and long-term wireless monitoring of an old roadway metallic bridge," *Engineering Structures*, vol. 176, pp. 585–605, 2018.

[5] Y. E. Harmanci, J. Michels, C. Czaderski, R. Loser, and E. Chatzis, "Long-term residual anchorage resistance of gradient anchorages for prestressed CFRP strips," *Composites Part B*, vol. 139, pp. 171–184, 2018.

[6] A. Hosseini, E. Ghafoori, M. Motavalli, A. Nussbaumer, X. Zhao, R. Al-Mahaidi, and G. Terrasi, "Development of prestressed unbonded and bonded CFRP strengthening solutions for tensile metallic members," *Engineering Structures*, vol. 181, pp. 550–561, 2019.

[7] G. Liu, B. Li, J. Bao, S. Cheng, Q. Meng, and S. Zhao, "Case study on prestressed CFRP plates applied for strengthening hollow-section beam removed from an old bridge," *Polymers*, vol. 15, no. 3, p. 549, 2023.

[8] J. D. Jimenez-Vicaria, M. D. Gomez-Pulido, and D. Castro-Fresno, "Numerical and experimental evaluation of a CFRP fatigue strengthening for stringer-floor beam connections in a 19th century riveted railway bridge," *Metals*, vol. 11, no. 4, p. 603, 2021.

[9] S. Chataigner, M. Wahbeh, D. Garcia-Sanchez, et al., "Fatigue strengthening of steel bridges with adhesively bonded CFRP laminates: Case study," *J. Compos. Constr.*, vol. 24, no. 3, 2020.

[10] H. Pallempati, E. Beneberu, and N. Yazdani, "Evaluation of external FRP-concrete bond in repaired concrete bridge girders and columns," *Innov. Infrastruct. Solutions*, vol. 1, p. 12, 2016.

[11] J. Yao, J. G. Teng, and L. Lam, "Experimental study on intermediate crack debonding in FRP-strengthened RC flexural members," *Adv. Struct. Eng.*, vol. 8, no. 4, pp. 337–359, 2005.

[12] T. Hassan and S. Rizkalla, "Flexural strengthening of prestressed bridge slabs with FRP systems," *PCI Journal*, vol. 47, no. 1, pp. 76–93, 2002.

[13] S. R. Abid, K. Al-lami, and S. K. Shukla, "Critical review of strength and durability of concrete beams externally bonded with FRP," *Cogent Eng.*, vol. 5, p. 1525015, 2018.

[14] R. Thamrin, Z. Zaidir, and S. Desharma, "Debonding failure analysis of reinforced concrete beams strengthened with CFRP plates," *Polymers*, vol. 13, no. 16, p. 2738, 2021.

[15] R. El-Hacha and M. Gaafar, "Flexural strengthening of reinforced concrete beams using prestressed, near-surface-mounted CFRP bars," *PCI Journal*, vol. 56, no. 4, pp. 134–151, 2011.

[16] K. Mahmoud, S. Foubert, and E. El-Salakawy, "Strengthening of prestressed concrete hollow-core slab openings using near-surface-mounted CFRP reinforcement," *PCI Journal*, vol. 62, no. 4, pp. 45–57, 2017.

[17] V. L. Kuntal, M. Chellapandian, and S. S. Prakash, "Efficient near surface mounted CFRP shear strengthening of high strength prestressed concrete beams – an experimental study," *Compos. Struct.*, vol. 180, pp. 16–28, 2017.

[18] M. Obaydullah, M. Z. Jumaat, U. J. Alengaram, M. H. Kabir, and M. H. Rashid, "Combining EBR CFRP sheet with prestressed NSM steel strands to enhance the structural behavior of prestressed concrete beams," *J. Civil Eng. Manage.*, vol. 27, no. 8, pp. 637–650, 2021.

[19] J. W. Schmidt, J. D. Sørensen, and C. O. Christensen, "In situ concrete bridge strengthening using ductile activated NSMR CFRP system," *Buildings*, vol. 12, no. 12, p. 2244, 2022.

[20] F. A. Megahed, M. H. Seleem, A. A. M. Badawy, et al., "The flexural response of RC beams strengthened by EB/NSM techniques using FRP and metal materials: A state-of-the-art review," *Innov. Infrastruct. Solutions*, vol. 8, p. 289, 2023.

[21] J. Qureshi, "A review of fibre reinforced polymer bridges," *Fibers*, vol. 11, no. 5, p. 40, 2023.

[22] L. Tang, "Maintenance and inspection of fiber-reinforced polymer (FRP) bridges: A review of methods," *Materials*, vol. 14, no. 24, p. 7826, 2021.

[23] J. Albuja-Sánchez, A. Damián-Chalán, and D. Escobar, "Experimental studies and application of FRPs in civil infrastructure systems: A state-of-the-art review," *Polymers*, vol. 16, no. 2, p. 250, 2024.

[24] Study on fatigue durability of corroded steel girder ends repaired with CFRP, *Int. J. Steel Struct.*, vol. 23, pp. 1500–1512, 2023.

[25] A. A. K. Sharba, D. H. Hussain, and M. A. Abdulhussain, "Retrofitting of RC beams using FRP techniques: A review," *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 1090, p. 012054, 2021.

[26] B. W. Jasim and A. A. Al-Azzawi, "Performance of concrete beams strengthened with FRP rods: A review," *Al-Salam J. Eng. Technol.*, vol. 4, no. 2, 2024.

[27] A state-of-the-art review on RC beams with openings retrofitted with FRP, *Int. J. Adv. Struct. Eng.*, vol. 8, pp. 253–267, 2016.

[28] H. Dai, C. Qiu, Y. Han, et al., "A review on stress performance of concrete beams with FRP bars instead of steel bars," *Int. Core J. Eng.*, 2025.

[29] FRP-strengthened RC beams: review of cracking and deflection models, *Mech. Compos. Mater.*, vol. 45, pp. 619–630, 2009.

[30] NDT evaluation of long-term bond durability of CFRP-structural systems applied to RC highway bridges, *Int. J. Adv. Struct. Eng.*, 2016.

[31] F. N. Catbas, et al., "Static and dynamic testing of a concrete T-beam bridge before and after CFRP retrofit," *Transp. Res. Rec.*, no. 1976, pp. 175–182, 2006.

[32] J. Wang, X. Su, and Q. Gao, "A review of the applications of CFRP reinforcements in civil engineering," *E3S Web Conf.*, 2025.

[33] B. Wu, S. Fu, Y. Gong, et al., "Dynamic monitoring of CFRP strengthened bridges: A distributed sensing approach under bridge–vehicle coupling," *Buildings*, vol. 15, no. 1, p. 76, 2025.