GLOBAL RESEARCH NETWORK

**AMERICAN Journal of Engineering, Mechanics and Architecture**
*Volume 2, Issue 11, 2024 ISSN (E): 2993-2637*

# Retrofitting of a Deteriorated Bridge Girder using CFRP Laminates

**Safa Myayad Naji, Hussam Ali Mohammed**
*Al-Furat AL. Awsat Technical University, AL- Musaib Technical College- Babylon, Iraq*

**Abstract:** In this study, the use of Carbon Fiber Reinforced Polymer (CFRP) laminates is investigated to strengthen old bridge girders. These girders weaken over time due to wear and environmental effects. CFRP offers a lightweight, strong reinforcement solution. The research investigates various bonding methods and laminate arrangements, testing the mechanical performance post-retrofitting effects. The results highlight the practical benefits of using CFRP, such as its ability to enhance stiffness and load capacity. Moreover, it is a cost-effective choice that minimizes traffic disruptions for older bridge systems.

**Keywords:** Bridge Girder, CFRP Laminates, reinforced concrete spans.

## Introduction:

Many state and local agencies must improve bridge infrastructure, especially for short—to medium-span bridges with steel supports and concrete decks. While much talk has been about how bridges deteriorate, their durability and long-term performance still need more emphasis. As a result, many bridges in the United States need to be more structurally deficient and functionally obsolete [1-3].

This study looked at improving the reinforced concrete spans of a bridge that faced heavy vehicle loads using Carbon Fiber Reinforced Polymer (CFRP) laminates. The initial work involved making a computer model of these concrete spans. We analyzed how the concrete would bend before and after strengthening it with CFRP laminates. The paper explains the retrofitting done on a reinforced concrete bridge aged 27year old, covering the analysis, design, construction, and monitoring after the repairs [4].

Reinforced concrete is widely used in building structures, and maintaining their safety is essential due to significant financial investments. The primary issue with reinforced concrete is the rusting of the internal steel. While metal plates are sometimes added to strengthen concrete beams, they can rust, complicate installation, and lead to early failures. Instead, fiber-reinforced polymer (FRP) composites are becoming popular for strengthening structures in civil engineering due to their strength, versatility, ease of installation, and corrosion resistance [5].

Repairing and reinforcing bridges in poor condition can extend their lifespan and support heavier loads. High-performance materials, especially CFRP composites, are ideal for these repairs due to their strength and lightweight properties, which help reduce labor costs. Promptly addressing issues like concrete cracks or rusting steel is crucial to maintaining the bridge's strength [6].

Bridge superstructures worldwide often suffer damage from impacts caused by over-height trucks. These impacts can lead to load restrictions or bridge closures due to structural failure, which risks collapse. While steel beams and girders can be repaired using heat-straightening, welding, or bolting in new parts, fixing RC and prestressed concrete (PC) beams is more challenging. Damage to these beams can include cracking, problems with reinforcement or prestressing strands, steel yielding, concrete spalling, and failures in joints and connections.

FRP laminates and fabrics have become popular for repairing and strengthening concrete girders in the last twenty years. CFRP composites are favored because they do not rust, are durable, are easy to apply, and are cost-effective due to their high strength-to-weight ratio [7].

Maintenance, rehabilitation, and upgrading of structural members are critical in civil engineering. Many structures built under older design codes are now considered structurally unsafe by current standards. Replacing these deficient elements is costly and time-consuming, making strengthening a preferred method to improve load-carrying capacity and extend service life. Infrastructure decay due to premature deterioration has prompted the exploration of various repair and strengthening processes. A significant challenge is selecting an appropriate strengthening method that enhances structural strength and serviceability while considering constructability, building operations, and budget constraints. Structural strengthening is often necessary to ensure elements can safely resist internal forces such as flexure, shear, axial, and torsion. This can be achieved by reducing these forces or enhancing the member's resistance. Common techniques include section enlargement, externally bonded reinforcement, post-tensioning, and supplemental supports.

Strengthening systems can help structures handle internal forces better. They can use either passive or active methods.

Passive strengthening only works when extra loads are added beyond what was present when the system was installed. Examples include attaching steel plates or FRP composites to structural parts.

Active strengthening responds right away by adding external forces that counter internal forces. This can happen through external post-tensioning systems or lifting the structure to relieve or shift existing loads.

Both methods face a main challenge: ensuring the new strengthening parts work well with the existing structure [8].

Traditional methods for strengthening structures can be inefficient and costly, highlighting the need for alternatives. FRP composites are strong, lightweight, corrosion-resistant, and adaptable for various applications. Initially used in the 1940s for shipbuilding and aerospace due to high costs, ongoing research has made FRP more accessible for construction, particularly in enhancing Reinforced Concrete (RC) and steel bridges. While its initial cost may be higher, FRP is often more cost-effective when considering labor and downtime savings. Other methods, like Shape Memory Alloys (SMA), are still being developed to compete with FRP's capabilities [9].

The growing population and economy are putting pressure on old infrastructure. We need to update our transportation system to keep up with this demand. Bridge owners and engineers seek efficient and affordable ways to repair bridges and improve their load capacity. These solutions should be easy to implement and help extend the life of the bridges. Over the past twenty years, new techniques for strengthening bridges have met modern traffic needs [10].

Bridges often have a shorter lifespan because the steel bars inside the bridge decks can corrode. This corrosion and cracks from heavy loads can occur when traffic increases beyond what the bridge was originally designed for. Workers usually patch damaged areas or replace the entire deck when repairing bridges. One alternative to replacing old decks is using FRP Composites (FRPC). Studies have shown that FRPC decks can be a good substitute for traditional reinforced concrete decks and offer several benefits [11].

Many steel bridges wear significantly due to long-term use and environmental exposure (Liu, Silva, & Nanni, 2001). To help these bridges, engineers can add steel plates to the rafters to strengthen them, insert new girders between the existing ones (McRae & Ramey, 2003), or replace the entire bridge structure. CFRP materials, which are lightweight and commonly used in the aerospace industry, are now being explored for bridge repair. Bridge inspections mostly rely on visual checks, which often miss important details about strain and stress on the structure. Besides using CFRP laminates for repair, engineers also use Finite Element (FE) modeling techniques to see how effective these methods are [12].

Fixing all the bridges that are no longer safe to use is too expensive, so retrofitting is necessary. Techniques like reinforced concrete and steel jacketing help repair weak bridge columns. In the last ten years, FRP have become popular among researchers and bridge owners as a new material for strengthening reinforced concrete bridge parts [13].

## LITERATURE REVIEW

Sachin Devadkar investigated a different technique for retrofitting steel bridge girders utilizing laminate strips made of carbon fiber reinforced polymers (CFRP). It is suggested that this approach is more cost-effective and efficient than conventional techniques. The study emphasizes CFRP laminates' benefits, which include their durability and low weight, which make handling and maintenance simpler. The elastic and ultimate capacities of the beams were shown to have significantly improved throughout experimental and analytical study, which included testing on five composite beams and around 100 finite element models. According to the study, a well-designed AASHTO rehabilitation approach that takes these factors into account can result in a successful bridge structure. These criteria are essential for the CFRP rehabilitation technique's efficacy [12].

Talat Salama investigated the use of Carbon Fiber Reinforced Polymers (CFRP) laminate strips as a substitute for conventional steel bridge girder retrofit techniques. This approach is thought to be more cost-effective and efficient, with benefits including durability and light weight that make handling and maintenance simpler. In addition to testing five composite beams and creating about 100 finite element models, the research involved both experimental and analytical work. The elastic and ultimate capabilities of the beams significantly improved, according to the results. According to the study's findings, certain characteristics are essential to the CFRP technique's efficacy, and a good bridge construction can result from an AASHTO rehabilitation approach that takes these elements into account [3].

Khondaker Sakil Ahmed studied how bridges in Bangladesh are falling apart because they're getting old, the weather is rough on them, and there's a ton of traffic. They focused on a concrete bridge and used non-destructive testing and math to figure out how to fix it. They used epoxy injections, micro mortars, and U-shaped CFRP sheets to make the bridge strong again. They did a bunch of tests to make sure the repairs met the standards and were able to fix the girder bridge. After the repairs, the bridge didn't bend as much and returned to being as good as new. It's been a while since they did the repairs, and the bridge hasn't had any more problems, which shows that their fixes worked [14].

Ching Chiaw Choo looked into ways to strengthen concrete bridges for heavy trucks by using CFRP sheets. He made a computer model to test how much force the bridge could take and analyzed how flexible it was with and without the reinforcement. The study showed that the bridge was much stronger when pushed to its limits, making it safer against heavy loads, but it didn't make much of a difference at normal loads. It also found that some trucks were too heavy, causing cracks in the bridge [7].

Khaled Galal discussed how old bridges are a problem and how using FRP composite systems is better than regular techniques for fixing them. He shared some research from Concordia University about how FRP makes bridges stronger and also talked about the materials you need to use and the things that might get in the way of fixing bridges in the future [9].

T.P. Meikandaan looked into fixing reinforced concrete beams with damage using CFRP laminates. The study included checking control and damaged beams with different laminate amounts and looking at how damaged they were, how wide the laminates were, and how strong the concrete was. The tests were done on beams held up and weighed at two points. The findings showed that the laminate width impacted how the beams failed, like peeling and the laminate sticking [8].

Abheetha Peiris looked into using CRP RodPanels to strengthen concrete structures, especially for fixing beams on a bridge in Kentucky that was hit by a big truck. CRPs are easy to use and don't cause much traffic trouble, so following AASHTO rules for bridge fixes is important. The study also checked how well CRPs can handle different amounts of weight, showing why they're a good choice for bridge repairs [6].

RK. Manikandan's study concentrated on enhancing reinforced concrete beams by utilizing single-layer CFRP laminates and adhesives: epoxy, orthophthalic resin, and ISO resin. Following two-point loading tests, the beams reinforced with epoxy or G.P. adhesives exhibited increased load capacities and larger deflections compared to the control beams or those reinforced with ISO resin. Key findings included ultimate load capacities: CB1: 24 KN, B3: 25.5 KN, B4: 49.5 KN, B5: 52.5 KN, B6: 43.5 KN, with increases of 94.12%, 105.88%, and 70.59% for beams B4, B5, and B6, respectively. Maximum deflections were: CB1: 7.38 mm, B3: 8.8 mm, B4: 10 mm, B5: 23 mm, B6: 10 mm. The failure modes noted included mid-span debonding for B4 and B6 and a mix of compression failure and mid-span debonding for B5 [4].

Adel ElSafty studied using CFRP to repair prestressed concrete bridge girders damaged by vehicle collisions. He tested 13 half-scale AASHTO Type II PS girders under static and fatigue loads, simulating damage by cutting through the concrete and a prestressing strand. The repair methods involved CFRP laminates and transverse U-wraps. His findings indicated that well-designed CFRP systems can effectively restore the girders' strength to withstand repeated loads [15].

Samuel Sherry highlights the challenges aging bridges face with increased truckloads, which can jeopardize their integrity. While updates are generally preferred over full replacements, removing steel plates can cause lane closures and corrosion. A promising alternative is carbon CFRP laminates, which are lightweight and strong. Recent research on a new High Modulus (H.M.) CFRP for steel shows it enhances strength and stiffness in corrosive conditions. This marks the first use of HM CFRP strand sheets in the U.S. to update worn-out steel bridges, confirming that CFRP can effectively strengthen and stiffen them for future projects [16].

Osman Hag-Elsafi's report details using FRP laminates to strengthen an old T-beam bridge in South Troy, New York, which faced safety issues from moisture and salt damage. With no design documents available, FRP laminates were chosen for repair. Load tests before and after installation showed a slight reduction in rebar stress and improved load distribution. The FRP system was cost-effective and minimized traffic disruption [17].

Ahmed Sabri Abd-El-Meguid researched using CFRP laminate strips as a budget-friendly alternative to conventional methods for enhancing steel bridge girders. CFRP laminates are lightweight, robust, and manageable. The study included experiments and analyses, testing five composite beams and developing 100 finite element models. The findings indicated significant enhancements in the strength and load-bearing capacity of the beams. The research highlighted that specific factors are essential for effective CFRP repair. A design that adheres to AASHTO guidelines and considers these factors would enhance bridge structures [18].

Julien Michel studied how to strengthen bridges in Poland using prestressed carbon-fiber-reinforced polymer (CFRP) strips with a special anchoring design. This method requires only a temporary support frame, not metallic bolts and plates. Two long beams were tested: one was standard, and the other was reinforced with CFRP strips. The reinforced beam showed good flexibility and increased how much weight it could carry. It improved cracking resistance and ultimate loads by 16% and 25%, respectively. Although there were some practical challenges, the results are promising for future bridge upgrades [19].

Ching Chiaw Choo inspected the Louisa-Fort Gay Bridge and found cracks in the concrete beams. The analysis showed that trucks often exceeded the weight limit, putting too much stress on the bridge. In 2003, experts recommended installing CFRP laminates to strengthen the bridge. By 2006, monitoring with crack gauges showed no movement, proving that the repairs effectively extended the bridge's life [20].

Gopal L. Rai discussed the increasing necessity of repairing reinforced concrete structures. While steel was traditionally used for these repairs, FRP systems made from carbon fibers and epoxy resin are now preferred due to their strength, lightweight nature, and thin sheets. The paper presents four examples of FRP-implemented bridges, showcasing their efficiency in expediting repairs and minimizing traffic disruptions [21].

Catalin Andrei Neagoe researched ways to strengthen reinforced concrete structures using CFRP laminates. He conducted experiments at the Polytechnic University of Catalonia, analyzing factors like load displacement, deformation, and stress distribution in retrofitted beams. His findings demonstrated that CFRP laminates effectively enhance the bending performance of concrete beams, aligning closely with theoretical predictions [22].

Osama Ali studied RC highway bridges strengthened with CFRP laminates, focusing on factors like CFRP thickness and concrete cover. His research tackled increased live loads, chloride corrosion, and CFRP aging, utilizing Monte Carlo simulation and the First Order Reliability Method (FORM) to assess reliability against failure modes like concrete crushing and CFRP debonding. Findings showed that pitting corrosion significantly shortens bridge lifespan, suggesting a reliability target of $\beta = 4.2$, which exceeds the AASHTO standard of $\beta = 3.5$ without additional CFRP. The study underscores the reliability of CFRP-strengthened girders in tough conditions, particularly the impact of traffic volume on the initial reliability index [23].

Huy Pham focused on using FRP to strengthen RC structures, finding that high shear stresses can cause FRP to detach despite advancements in adhesives. The study tested eight RC beams and identified two separation types: at the ends and in the middle. Researchers confirmed two theoretical models predicting the ultimate loads for FRP separation and developed a non-linear finite element model to analyze beam behavior. They identified two brittle failures, end separation, and flexure-shear cracks, validating their theoretical models [24].

David Schnerch raised concerns about steel bridges, focusing on reduced load ratings and expensive repairs. This study investigates strengthening steel-concrete composite beams with high-modulus CFRP laminates. It conducted two flexural tests: one on large beams (6400 mm) with varying CFRP elastic moduli (640 GPa and 440 GPa) and another on smaller beams (3050 mm) to evaluate strain distribution. Results show that prestressed CFRP laminates enhance flexural stiffness while allowing flexibility. The study also found that high-modulus CFRP improves stiffness and strength under overloading, reducing damage compared to non-strengthened beams, with effective bonding at the steel-CFRP connection [25].

Sharayu D. Holey focused on rehabilitating and strengthening old structures using advanced materials, a process known as retrofitting. This is essential to extend the lifespan of reinforced concrete structures, which can deteriorate due to chemical agents, thermal stresses, improper design, and unexpected loads. High tensile strength fibers, such as glass and carbon fibers, enhance new and old structures. Retrofitting is particularly important for multi-span bridges to prevent further damage or collapse. The research involves extensive studies to identify damage causes and provide appropriate solutions to ensure long-lasting, strong structures capable of supporting heavy loads. Note that concrete that lost strength due to fire can regain about 98% of its original strength with two layers of wrapping. Adding more layers can further increase the strength [26]

**Conclusion:**

1. Retrofitting degraded bridge girders with CFRP laminates enhances structural performance by increasing load capacity and flexural strength, providing corrosion resistance, and being lightweight.

2. This method minimizes disruption during retrofitting, making it a practical solution for preserving and modernizing aging bridge infrastructure, ensuring safety and reliability.

**References**


1. (Wipf T. J., Phares, Klaiber, & Lee, 2003).
2. (Ramey & Wright, 1997)
3. Dr. Talat Salama and Mr. Ahmed Abd-El-Meguid Strengthening Steel Bridge Girders Using CFRP
4. Retrofitting of reinforced concrete beams using CFRP with various adhesive R.K. Manikandan , a K. Shunmugapriya , b c c c J. Arunprasad , S. Sugumar , D. Manikandan Reference :
5. Rapid Retrofit and Strengthening of Bridge Components Abheetha Peiris, Ph.D., P.E. Issam E. Harik, Ph.D.
6. Design and Construction of CFRP Rod Panel Retrofit for Impacted R.C. Bridge Girders D Abheetha Peiris 1,* and Issam Harik 2
7. Flexural retrofit of a bridge subjected to overweight trucks using CFRP laminates Ching Chiaw Choo, Tong Zhao, Issam Harik
8. STUDY OF DAMAGED RC BEAMS REPAIRED BY BONDING OF CFRP LAMINATES T.P. MEIKANDAAN,and Dr. A. RAMACHANDRA MURTHY
9. FRP Retrofitting of Bridges Dr. Khaled Galal
10. Report on Techniques for Bridge Strengthening Joseph L. Hartmann, PhD, P.E.
11. Strengthening of Deteriorating Decks of Highway Bridges in Indiana Using FRPC Elisa D. Sotelino, Ming-Hung Teng
12. A Survey on Strengthening Steel Bridge Girders Using CFRP Sachin Devadkar, N. C. Dubey
13. RETROFIT OF RECTANGULAR BRIDGE COLUMNS USING CFRP WRAPPING Mesay A. Endeshaw, Mohamed ElGawady, Ronald L. Sack, and David I. McLean
14. Repair and Retrofitting of Concrete Bridge Girder Using Epoxy, Micro Mortar, and CFRP Sheets Khondaker Ahmed1*, Md Moniruzzaman 2, and Kaniz Rupa 3
15. Behavior of Laterally Damaged Prestressed Concrete Bridge Girders Repaired with CFRP Laminates Under Static and Fatigue Loading Adel ElSafty1),*, Matthew K. Graeff2), and Sam Fallaha3)
16. Carbon Fiber Reinforced Polymer Retrofits to Increase the Flexural Capacity of Deteriorated Steel Members Samuel Sherry
17. Strengthening of Route 378 Bridge Over Wynantskill Creek In New York Using FRP Laminates OSMAN HAG-ELSAFI
18. Strengthening and Rehabilitation of Steel Bridge Girders Using Strengthening and Rehabilitation of Steel Bridge Girders Using CFRP Laminates Ahmed Sabri Abd-El-Meguid
19. Prestressed CFRP Strips for Concrete Bridge Girder Retrofitting: Application and Static Loading Test Julien Michels, Ph.D.1; Michał Staśkiewicz2; Christoph Czaderski, Ph.D.3; Renata Kotynia, Ph.D.4; YunusEmreHarmanci5;andMasoudMotavalli, Ph.D., M.ASCE

20. Retrofit of the Louisa-Fort Gay Bridge using CFRP Laminates Ching Chiaw Choo
21. Retrofitting Of Bridges Using FRP Composite System Gopal L. Rai
22. CONCRETE BEAMS REINFORCED WITH CFRP LAMINATES Catalin Andrei Neagoe
23. Comparative durability analysis of CFRP-strengthened RC highway bridges Osama Ali, David Bigaud, Emmanuel Ferrier
24. Flexural Retrofitting of Concrete Bridge Beams Using CFRP Fabrics Huy Pham and Riadh Al-Mahaidi
25. STRENGTHENING STEEL-CONCRETE COMPOSITE BRIDGES WITH HIGH MODULUS CARBON FIBER REINFORCED POLYMER (CFRP) LAMINATES David Schnerch, Mina Dawood, Emmett A. Sumner, and Sami Rizkalla
26. STRENGTH ENHANCEMENT OF EXISTING MULTI-SPAN BRIDGE USING FRP LAMINATES
27. Sharayu D. Holey1 and S. A. Rasal
28. no sources in the current document.