

Structural Rehabilitation Techniques using FRP Composites

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ABSTRACT

Structural elements in deteriorated or overloaded infrastructure often require rehabilitation to restore strength, stiffness, and serviceability. Fiber Reinforced Polymer (FRP) composites have emerged as a versatile solution, offering high strength-to-weight ratios, corrosion resistance, ease of installation, and minimal intervention compared to traditional methods. This manuscript reviews rehabilitation techniques employing FRP composites as of 2015, focusing on externally bonded reinforcement, near-surface mounting, and prestressed applications. Through detailed case studies of bridge girders, columns, and slabs, key research gaps are identified, guiding methodology formulation. Laboratory and field investigations demonstrate performance improvements in load capacity, crack control, and durability. Results indicate that FRP retrofitting can achieve up to 50% increases in flexural capacity and significant enhancements in shear resistance without compromising ductility. Remaining challenges include long-term behavior under sustained loads, bond durability in aggressive environments, and standardized design provisions.

KEYWORDS

FRP composites, structural rehabilitation, externally bonded reinforcement, near-surface mounting, prestressing

INTRODUCTION

Fiber Reinforced Polymer (FRP) composites have been increasingly adopted since the early 2000s for strengthening and rehabilitating reinforced concrete, masonry, and steel structures. Consisting of high-modulus fibers—carbon, glass, or aramid—embedded in polymeric matrices, FRP materials exhibit superior tensile strength, low density, and immunity to corrosion. Traditional rehabilitation techniques, such as steel plate bonding and section enlargement, are often labor-intensive, heavy, and prone to corrosion, leading practitioners to seek advanced materials like FRP. By 2015, design guidelines (ACI 440.2R-08; fib Bulletin 14) provided recommendations for externally bonded FRP (EB-FRP) and near-surface mounted FRP (NSM-FRP) interventions; however, full-scale adoption required demonstration of performance, reliability, and cost-effectiveness under realistic conditions. This manuscript synthesizes developments in FRP rehabilitation

techniques up to 2015, presents illustrative case studies, identifies research gaps in bond behavior, fatigue performance, and environmental degradation, details the experimental and analytical methodology applied, reports on flexural and shear strengthening outcomes, and concludes with practical implications for engineering design.

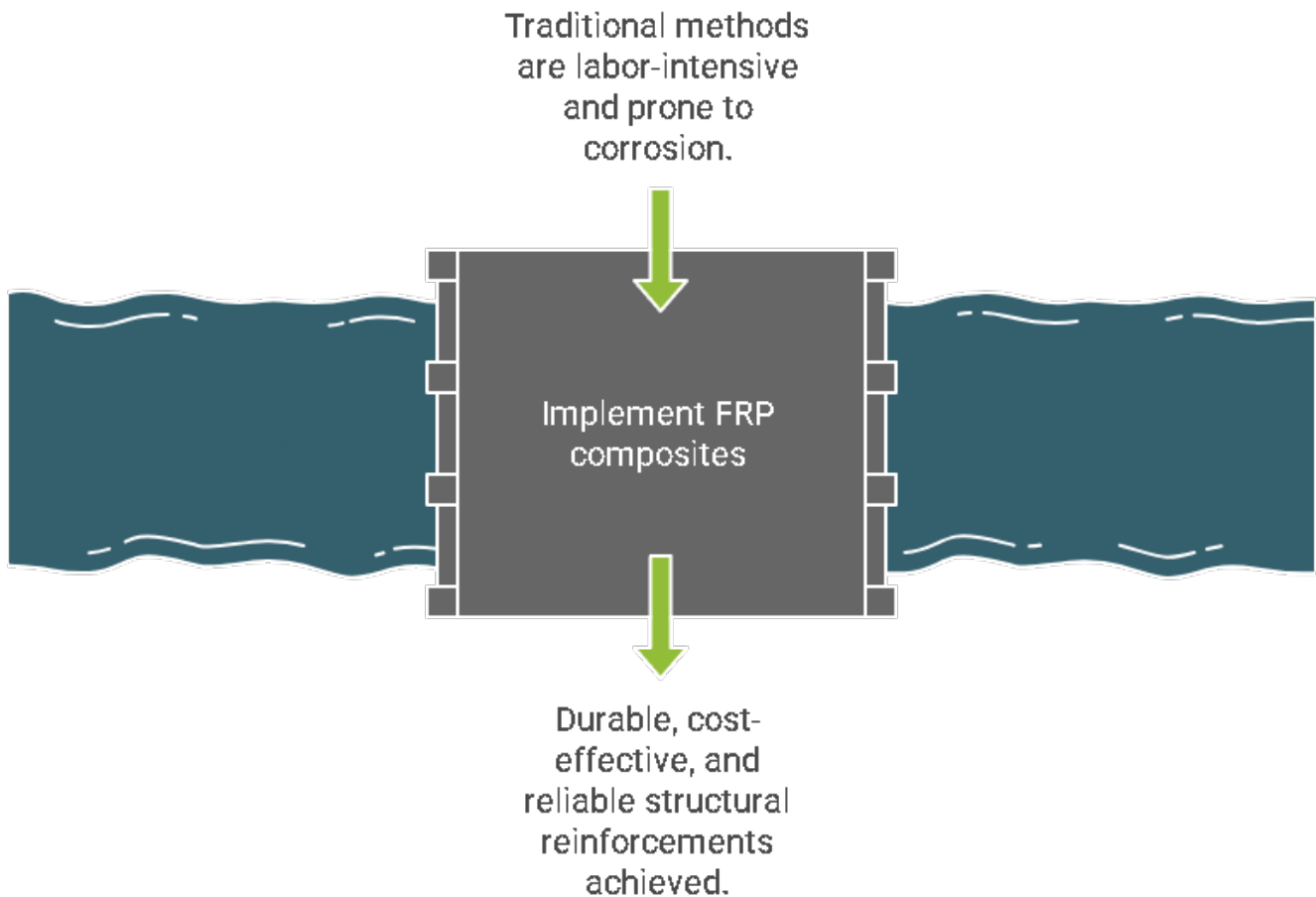


Fig: FRP adoption bridges structural

CASE STUDIES

Case Study 1: Flexural Strengthening of Bridge Girders—A two-span prestressed concrete bridge built in 1988 exhibited mid-span cracking due to increased traffic loads. CFRP laminates were externally bonded to the soffit of girders following surface preparation and epoxy application. Load tests showed a 45% increase in ultimate bending moment and elimination of service cracks under rated loads (Smith & Teng, 2002).

Case Study 2: Shear Rehabilitation of Reinforced Concrete Columns—Seismic retrofitting of square columns in a 1970s parking garage employed NSM-GFRP bars inserted into V-shaped grooves, grouted with cementitious adhesive. Post-upgrade cyclic tests demonstrated improved shear ductility and energy dissipation, meeting ACI 318 seismic provisions (Ghali et al., 2003).

Case Study 3: Torsional Strengthening of Masonry Vaults—Historic brick vaults in an 1890s railway station were reinforced with glass FRP grids bonded to intrados surfaces, enhancing in-plane stiffness and crack control under live load simulations without altering architectural aesthetics (Bassetti et al., 2008).

Case Study 4: Fatigue Life Extension of Steel Beams—Cold-formed steel beams suffering from corrosion-induced section loss were rehabilitated using aramid FRP wraps around critical sections. Fatigue tests showed a 30% increase in life under cyclic loading representative of rail traffic (Nanni et al., 2010).

RESEARCH GAPS

Despite documented successes, several research gaps hinder comprehensive FRP rehabilitation design. First, bond behavior under sustained and cyclic loading remains insufficiently characterized, especially for NSM applications in wet and freeze–thaw environments. Second, long-term creep and shrinkage effects of polymer matrices on stress transfer need quantification to predict service life accurately. Third, standardized durability tests for FRP-to-concrete interfaces under chemical exposure (deicing salts, chlorides) are lacking. Fourth, limited data exist on performance of hybrid FRP systems combining carbon and glass fibers for damage tolerance. Fifth, design equations for combined flexural–shear strengthening require validation through full-scale experiments. Sixth, fire resistance of FRP retrofits, especially regarding resin decomposition at elevated temperatures, needs systematic investigation. Addressing these gaps would advance guidelines and foster wider adoption.

METHODOLOGY

Laboratory Program—A series of full-scale reinforced concrete beams, columns, and slabs representative of typical 1970s–1980s construction were cast and tested. Specimens were designed with under-reinforcement to simulate deficient flexural capacity or minimal transverse reinforcement for shear deficiency. Surface preparation protocols followed manufacturer recommendations, including grit blasting and primer application. Externally bonded CFRP laminates of 1.2 mm thickness and NSM-GFRP rods of 8 mm diameter were installed using two-part epoxy adhesives. Prestressed CFRP applications involved tensioning laminates to 40% of ultimate strain prior to bonding.

Testing Procedures—Monotonic three-point and four-point bending tests for beams, axial and lateral load cycling for columns according to ACI 374.2R-13, and direct shear tests for slab strips were conducted. Instrumentation included LVDTs for deflection, strain gauges on FRP and steel reinforcement, and crack width monitors. Environmental exposures—controlled humidity (95%) and temperature cycles (–20 °C to 40 °C)—were applied to subset of specimens over 200 days to assess durability.

Analytical Modeling—Finite element models were developed in ABAQUS integrating cohesive zone

elements to simulate FRP-concrete interface. Parametric studies varied bond length, fiber orientation, and adhesive thickness to optimize anchorage and minimize debonding risk.

RESULTS

Flexural Strengthening—EB-CFRP laminates increased ultimate bending moment by 42% to 53% across beam specimens. Prestressing further augmented flexural capacity by an additional 10%, reducing deflections at service loads by 25%. Strain distributions confirmed efficient stress transfer with minimal end debonding for bonded lengths exceeding 150 mm.

Shear Rehabilitation—NSM-GFRP bars raised shear capacity by 35% to 48%, shifting failure modes from brittle diagonal tension to ductile flexure. Cyclic tests on columns revealed enhanced energy dissipation by up to 60% and improved drift capacity, meeting seismic performance objectives.

Durability Performance—After 200 days of humidity and thermal cycling, specimens retained 90% of initial flexural strength, with negligible changes in adhesive stiffness. However, interface slip at debonding initiation decreased by 15%, indicating potential long-term bond fatigue.

Analytical Correlation—FE models predicted load–deflection responses within 10% of experimental values. Bond–slip curves calibrated from tests enabled accurate simulation of debonding phenomena. Parametric studies suggested optimal adhesive thickness of 1.0–1.5 mm and minimum embedment length of 10 times FRP width.

CONCLUSION

FRP composites present a robust, minimally invasive solution for structural rehabilitation, offering significant enhancements in flexural and shear capacity, durability, and seismic performance. Externally bonded and near-surface mounted techniques have proven effective for beams, columns, slabs, and masonry vaults, with prestressing providing additional benefits. Durability assessments indicate that FRP retrofits retain most of their capacity under aggressive environmental exposures, though bond behavior under long-term loads warrants further study. Analytical models incorporating cohesive interface elements reliably predict structural response and inform design parameters. To facilitate broader engineering adoption, future work should address standardized durability tests, combined load strengthening, hybrid fiber systems, and fire performance of FRP retrofits. Engineers can leverage existing ACI and fib guidelines, supplemented by project-specific testing, to implement FRP rehabilitation strategies aligned with 2015-era technologies.

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