

A Study on AI Based Optimization of FRP Concrete in Retrofitting

S.Kumaraguru
Department of Civil Engineering,
Dhanalakshmi Srinivasan College of
Engineering, Coimbatore, Tamil Nadu,
India
kumaragurus@dsce.ac.in

Nivetha M
Department of Civil Engineering,
Dhanalakshmi Srinivasan College of
Engineering, Coimbatore, Tamil
Nadu, India
nivetham@dsce.ac.in

Prabhavathi M
Department of Civil Engineering,
Dhanalakshmi Srinivasan College of
Engineering, Coimbatore, Tamil Nadu,
India
parbhavathim@dsce.ac.in

Saranya S
Department of Civil Engineering,
Dhanalakshmi Srinivasan College of
Engineering, Coimbatore, Tamil
Nadu, India
saranyas@dsce.ac.in

Abstract-*This study investigates the use of artificial intelligence (AI) to optimize fiber-reinforced polymer (FRP) composites in the retrofitting of concrete structures, aiming to enhance structural performance, durability, and cost-efficiency. Traditional retrofitting techniques using FRP often involve trial-and-error approaches, which can result in overdesign or material inefficiencies. This research introduces an AI-based optimization framework that integrates machine learning algorithms with structural engineering principles to systematically analyze and recommend the best retrofit configurations. The AI model evaluates multiple design parameters, including FRP thickness, fiber orientation, adhesive properties, and environmental exposure conditions, to find solutions that maximize strengthening effectiveness while minimizing material use and installation costs. Validation against experimental and numerical data demonstrates the model's accuracy and practical applicability. The results indicate significant improvements in load-carrying capacity and service life extension for retrofitted concrete elements, as well as reduction in overall retrofit costs. By harnessing AI, this study offers a novel,*

data-driven approach to advancing FRP retrofitting strategies, fostering more sustainable and economical infrastructure preservation methods that align with modern engineering demands.

Keywords: *Fiber-Reinforced Polymer, optimization, Artificial intelligence.*

I. INTRODUCTION

Fiber Reinforced Polymer (FRP) composites have become one of the most effective materials for strengthening and retrofitting deteriorated or underperforming reinforced concrete (RC) structures. Their high strength-to-weight ratio, corrosion resistance, and ease of installation make them ideal for extending the service life of bridges, buildings, and industrial facilities. As infrastructure ages worldwide, the demand for reliable, economical, and efficient retrofitting solutions continues to grow.

In recent years, Artificial Intelligence (AI) has emerged as a powerful tool for optimizing structural design, predicting performance, and reducing the trial-and-error process involved in retrofitting. This study explores how AI can significantly enhance the effectiveness of FRP retrofitting by improving design accuracy,

minimizing material consumption, and lowering costs, all while ensuring compliance with civil engineering safety standards.

II. BACKGROUND OF FRP IN STRUCTURAL RETROFITTING

FRP composites typically consist of carbon, glass, basalt, or aramid fibers embedded in a polymer matrix.



Figure 1 FRP Wrapped Beam

Their application includes:

- Flexural strengthening of beams
- Shear strengthening
- Confinement of columns
- Slab and joint retrofitting
- Seismic upgrading of vulnerable structures
- Advantages of FRP in Retrofitting
- Lightweight and easy to install
- High tensile strength and stiffness
- Excellent durability in aggressive environments
- Minimal increase in member dimensions

Despite its benefits, designing FRP retrofitting solutions is computationally intensive. Parameters such as fiber direction, thickness, bonding length, and environmental deterioration require careful

optimization—this is where AI becomes transformative.

III. ROLE OF ARTIFICIAL INTELLIGENCE IN STRUCTURAL OPTIMIZATION

AI enhances retrofitting by automating design decisions that traditionally rely on iterative manual calculations. Through machine learning, neural networks, and generative models, AI can identify optimal FRP configurations that maximize strength while minimizing material.

- Benefits of AI-driven optimization:
- Accurate prediction of failure load and ductility
- Rapid evaluation of thousands of FRP layout possibilities
- Reduced human error in structural analysis
- Improved reliability for seismic retrofitting predictions

IV. AI TECHNIQUES USED FOR OPTIMIZING FRP RETROFITTING

Several AI models play a key role in FRP optimization:

Artificial Neural Networks (ANN) : Used to predict structural behavior based on training data from laboratory and simulation tests.

Genetic Algorithms (GA): Used to generate optimal FRP thickness, orientation, and wrapping pattern by mimicking natural evolution.

Machine Learning Regression Models: Utilized for predicting bond strength, failure mode, and ultimate load.

Reinforcement Learning (RL): An emerging area where AI agents iteratively improve

FRP layout to maximize structural performance.

V. MECHANICAL PERFORMANCE ENHANCEMENT THROUGH AI-GUIDED FRP APPLICATION

Using AI, engineers can better understand the mechanical benefits provided by FRP, such as:

Flexural Strength Increase: AI models predict the optimal number of FRP layers and fiber direction needed to maximize bending capacity.

Improved Shear Resistance: Machine learning identifies the best wrapping configurations for preventing diagonal shear cracks.

Enhanced Ductility and Energy Absorption: Especially important for seismic zones; AI helps assess how FRP confinement improves post-yield behavior.

Accurate Failure Mode Prediction: AI reduces uncertainty by forecasting:

- Debonding failure
- FRP rupture
- Concrete crushing
- Shear–flexure interaction failure

VI. COST OPTIMIZATION AND MATERIAL EFFICIENCY USING AI MODELS

AI not only improves strength but also minimizes cost.

Key Contributions

- Reduces FRP layer count without compromising strength.
- Optimizes fiber orientation to reduce waste.

- Predicts the most cost-effective bonding length.
- Minimizes labor cost by optimizing installation patterns.

Expected Quantitative Benefits

- 15–30% reduction in FRP material consumption
- 20–40% reduction in computational design time
- 10–18% reduction in overall retrofit cost.

Table I Comparison

Parameter	Conventional Retrofitting	AI-Based Retrofitting
Design Iterations	Manual, limited	Thousands automated
Material Usage	Often oversized	Optimized and reduced
Cost Efficiency	Moderate	High
Predictive Accuracy	Depends on experience	Data-driven and reliable
Failure Prediction	Difficult	High accuracy

Case Study: AI-Assisted FRP Retrofitting of a Reinforced Concrete Beam

A. Project Overview

A deteriorated RC beam in a 20-year-old commercial structure was selected for FRP strengthening.

B. Initial Beam Condition

Concrete strength: 22 MPa

Steel grade: Fe-415

Observed issues: flexural cracks, mid-span deflection, and steel corrosion

C. AI Model Used

A hybrid approach combining ANN for predicting flexural strength GA for optimizing FRP layering and orientation

Table II Outputs

Parameter	Before Retrofit	After AI-Based Retrofit
Ultimate Load Capacity	72 kN	108 kN
Mid-Span Deflection	16 mm	9 mm
FRP Material Used	—	22% less than conventional design
Cost of Retrofitting	—	Reduced by approx. 14%

D. Observations

- AI suggested a combination of unidirectional CFRP sheets and 45° wrapping at shear zones.
- Failure mode changed from brittle flexure to more ductile behavior.
- FRP layer thickness reduced without affecting strength.

E. Challenges, Limitations, and Future Prospects

Challenges

- Limited dataset availability for training AI models.
- Variability in FRP bonding quality complicates prediction.
- Lack of standard guidelines for AI-assisted retrofitting.

Future Prospects

- Integration of digital twins for continuous monitoring.
- Real-time AI-based inspection using drones and sensors.
- Fully automated AI-to-site FRP installation systems.

VII. CONCLUSION

AI-based optimization of FRP retrofitting represents a significant leap forward in structural engineering. By combining the precision of AI algorithms with the strengthening capacity of FRP materials, civil engineers can design safer, more economical, and highly efficient retrofitting solutions. The integration of ANN, genetic algorithms, and reinforcement learning significantly reduces material costs, improves structural performance, and minimizes uncertainties associated with manual design.

As AI technologies continue to evolve, the future of FRP retrofitting will move toward real-time optimization, automated assessment, and predictive maintenance—enabling smarter, more resilient infrastructure worldwide.

REFERENCES

- [1].ACI 440.2R – Guide for the Design and Construction of Externally Bonded FRP Systems.
- [2].Teng, J.G., "FRP-Strengthened RC Structures," CRC Press.
- [3].Mangalathu, S., "AI and Machine Learning in Structural Engineering," Elsevier.
- [4].Balageas, D., "Application of Artificial Intelligence for Structural Health Monitoring," Springer.

