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Experimental Investigation of Fiber-Reinforced Polymer Strengthening of Concrete Columns

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KEYWORDS

ABSTRACT

Concrete columns are essential structural components in buildings, bridges, and other infrastructure. However, over time, they deteriorate due to aging, environmental exposure, and increased loading conditions. This study investigates the strengthening of concrete columns using Fiber-Reinforced Polymer (FRP) composites. FRP wrapping enhances the strength, ductility, and durability of concrete columns. The experimental investigation includes testing several concrete columns, both unconfined and confined with FRP sheets, under axial compressive loads. The results demonstrate significant improvements in load-bearing capacity and deformation resistance for the FRP-strengthened columns compared to unconfined ones. This research highlights the effectiveness of FRP as a practical solution for structural rehabilitation and retrofitting of concrete columns.

1. INTRODUCTION

Concrete is widely used in the construction industry due to its high compressive strength and durability. However, factors such as environmental degradation, seismic activities, and increased loads can reduce the performance of concrete structures. Traditional strengthening techniques, such as steel jacketing and concrete encasement, are often labor-intensive and susceptible to corrosion. Fiber-Reinforced Polymer (FRP) composites offer an innovative solution due to their high strength-to-weight ratio, corrosion resistance, and ease of application. FRP sheets or wraps are externally bonded to concrete columns, enhancing their load-carrying capacity and ductility. The purpose of this study is to experimentally evaluate the effectiveness of FRP strengthening by comparing the performance of unconfined and FRP-confined concrete columns. The results will help in assessing the viability of FRP composites for structural retrofitting applications.

2. LITERATURE SURVEY

The literature survey explores previous studies, experimental investigations, and research findings related to Fiber-Reinforced Polymer (FRP) strengthening of concrete columns. It covers the effectiveness of FRP confinement, material properties, failure modes, and performance improvements observed in experimental and numerical analyses.

Seismic Retrofit of RC Columns with Continuous Carbon Fiber Jackets

Key Findings:

◎ The study demonstrated that CFRP wrapping significantly enhanced the seismic resistance of reinforced concrete (RC) columns.

◎ FRP-confined columns exhibited improved ductility and post-yield deformation capacity.

◎ The research concluded that FRP confinement is effective for seismic retrofitting.

FRP-Strengthened RC Structures: Design and Experimental Findings

◎ The authors performed extensive experimental tests on FRP-strengthened RC columns.

◎ Results indicated a 35% to 60% increase in compressive strength of FRP-confined columns.

◎ The study also proposed design guidelines for FRP retrofitting based on experimental data.

Design-Oriented Stress-Strain Model for FRP-Confined Concrete

◎ Developed a stress-strain model for FRP-confined concrete columns based on experimental data.

◎ The model accurately predicted the strength enhancement and ductility of FRP-wrapped columns.

◎ Experimental validation showed strong correlation between the model and actual test results.

Influence of Confinement on Concrete Behavior

• The study explored the behavior of GFRP and CFRP-confined columns under axial load.

◎ Results demonstrated that CFRP offered higher strength enhancement due to its superior tensile properties.

◎ GFRP wraps provided moderate strength improvement but better deformation capacity.

Behavior of FRP-Confined Concrete Columns Under Eccentric Load

◎ Examined the performance of FRP-confined columns subjected to eccentric loading.

◎ Concluded that FRP wrapping significantly improved flexural strength and reduced crack propagation.

◎ The study also revealed that load eccentricity reduces confinement effectiveness.

Numerical Modeling of FRP-Confined Concrete Columns

◎ Developed a finite element model (FEM) to simulate the behavior of FRP-confined concrete columns.

◎ The model accurately predicted the stress-strain response and failure modes observed in experimental tests.

◎ Highlighted the influence of FRP layer thickness and wrap orientation on performance.

Strengthening of Concrete Columns with FRP

◎ Analytical and numerical modeling demonstrated that CFRP wrapping significantly increases the axial capacity of concrete columns.

◎ The study developed design equations for FRP strengthening applications.

◎ Concluded that multi-layer FRP wraps yield the highest strength enhancement.

Performance Comparison of CFRP and GFRP-Confined Concrete

◎ The study compared the performance of CFRP and GFRP wraps for column strengthening.

◎ CFRP provided higher strength enhancement due to its greater tensile strength.

◎ GFRP offered better deformation capacity, making it suitable for seismic retrofitting.

3. SYSTEM ANALYSIS

Existing System

In the conventional strengthening methods for concrete columns, the following techniques are commonly used,Steel Jacketing: Steel plates or jackets are applied around the column, increasing the strength and ductility.Concrete Jacketing: Additional layers of concrete are added, increasing the cross-sectional area and strength.External Post-Tensioning: Steel tendons are applied to create compressive forces, enhancing structural stability.

Drawbacks of the Existing System

• Corrosion Issues

- Heavy Weight
- Labor-Intensive
- Limited Ductility
- Reduced Aesthetic Appeal

Proposed System

The proposed system involves using Fiber-Reinforced Polymer (FRP) composites for strengthening concrete columns. FRP wraps or sheets are externally bonded to the surface of the column using epoxy resin. The key steps include,Surface Preparation: Cleaning and roughening the concrete surface for better adhesion.Epoxy Application: Applying a resin-based adhesive to bond the FRP sheets.Wrapping Process: Wrapping FRP sheets around the column in one or multiple layers, ensuring proper coverage and overlap.Curing: Allowing the epoxy to cure, forming a strong bond between the FRP and concrete surface.

Advantages of the Proposed System

- Increased Strength
- Enhanced Ductility
- Corrosion Resistance
- Lightweight
- Easy Application
- Cost-Effective
- Minimal Aesthetic Impact

IMPLEMENTATION

Materials

- Concrete Mix: Standard concrete mix with cement, sand, coarse aggregate, and water.
- Fiber-Reinforced Polymer (FRP):
- Types Used: Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP).
- Thickness: Typically 0.13 mm to 1 mm per layer.
- Epoxy Resin: Used as an adhesive to bond the FRP sheets to the concrete surface.
- Primer and Filler: To smoothen and prepare the concrete surface before FRP application.

Equipment

- Compression Testing Machine (CTM): For applying axial compressive load to the concrete columns.
- Surface Preparation Tools: Wire brushes, grinders, and sandpaper for cleaning and roughening the surface.
- FRP Wrapping Tools: Rollers, spatulas, and brushes for applying epoxy and wrapping FRP sheets.
- Measurement Instruments: Strain gauges, dial gauges, and displacement sensors for recording deformations.

Methodology and Experimental Procedure

Step 1: Column Preparation

1. Concrete Column Casting:

Concrete specimens are prepared by casting cylindrical or rectangular columns.

Standard dimensions:

◎ Cylindrical columns: 150 mm diameter × 300 mm height.

◎ Rectangular columns: 150 mm × 150 mm × 300 mm.

The concrete is cured for 28 days before testing.

2. Surface Preparation:

The surface of the concrete columns is cleaned and roughened using a wire brush or grinder.

This ensures better adhesion between the FRP sheets and the concrete surface.

Surface defects and cracks are filled with epoxy resin.

Step 2: FRP Wrapping Process

1. Epoxy Application:

A thin layer of epoxy resin is applied to the column surface.

2. FRP Sheet Cutting:

FRP sheets are cut to the required dimensions based on the column size.

3. Wrapping the Columns:

The FRP sheets are wrapped around the columns either in a single or multiple layers.

The overlaps (typically 100–150 mm) ensure continuous confinement.

4. Air Removal and Smoothing:

Air bubbles are removed by using rollers to ensure proper bonding.

5. Curing:

The wrapped columns are allowed to cure for 24–48 hours at room temperature.

In some cases, heat curing is applied to accelerate the epoxy hardening process.

Step 3: Axial Compression Testing

1. Test Setup:

The columns are placed in a Compression Testing Machine (CTM).

Strain gauges and displacement sensors are attached to measure deformation.

2. Loading Procedure:

An axial compressive load is applied gradually at a constant rate.
The load and deformation readings are recorded continuously.
3. Failure Observation:
The failure mode of the column is carefully observed (cracking pattern, crushing, and FRP delamination).
Testing and Results Analysis
Parameters Measured:
• Axial Load Capacity: The maximum load-bearing capacity before failure.
• Deformation and Ductility: The displacement and strain capacity before failure.
• Failure Mode:
Unconfined columns: Brittle failure (sudden cracking and crushing).
FRP-confined columns: Gradual failure with higher ductility.

CONCLUSION

The experimental investigation demonstrates that Fiber-Reinforced Polymer (FRP) strengthening significantly improves the structural performance of concrete columns. The FRP-confined columns exhibit higher compressive strength, enhanced ductility, and improved resistance to deformation compared to unconfined columns. The study concludes that FRP wrapping is an effective and practical solution for retrofitting and strengthening deteriorated or under-designed concrete structures.The use of FRP offers several advantages over traditional strengthening methods, including lightweight application, corrosion resistance, and superior mechanical performance. This technology is particularly beneficial for seismic retrofitting, infrastructure rehabilitation, and extending the service life of concrete structures.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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