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Dynamic Performance of Concrete Columns Retrofitted with FRP using Segment Pressure Technique

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Abstract: This study investigates the dynamic performance of reinforced concrete columns retrofitted with Fiber-Reinforced Polymer (FRP) using the Segment Pressure Technique (SPT). The experimental program involved dynamic loading tests on retrofitted and control specimens to evaluate improvements in strength, ductility, and energy absorption. Results demonstrate that the SPT significantly enhances the dynamic behavior of concrete columns by improving confinement efficiency and delaying failure. The findings confirm the effectiveness of this retrofitting approach for improving seismic and impact resistance in structural applications.
Keywords: Fiber-Reinforced Polymer (FRP) retrofitting, Concrete columns (CC), Segment Pressure Technique (STP), Dynamic performance (DP), Seismic resistance (SR).

I. INTRODUCTION

Reinforced concrete (RC) columns are susceptible to failure under dynamic loads such as earthquakes and impacts, making retrofitting essential for structural safety. Fiber-Reinforced Polymer (FRP) is widely used for strengthening due to its high strength and corrosion resistance. However, conventional FRP wrapping methods may be less effective under dynamic conditions. The Segment Pressure Technique (SPT) offers improved confinement and load transfer by applying localized pressure segments, enhancing performance under such loads. This study examines the dynamic behavior of FRP-retrofitted RC columns using SPT, aiming to improve strength, ductility, and energy absorption.

II. SOFTWARE USED

To complement the experimental analysis, numerical simulations and data processing were conducted using the following software tools:

1) *ANSYS / ABAQUS:* Used for finite element modeling (FEM) to simulate the dynamic response of retrofitted columns and validate experimental results.
2) *MATLAB:* Employed for data analysis, signal processing of dynamic test results, and plotting response curves.
3) *AutoCAD / SolidWorks***:** Used for preparing detailed schematics and modeling test setups and retrofitting configurations.
4) *Excel:* Utilized for organizing test data, performing basic calculations, and generating summary tables.

III. METHODOLOGY

This research adopted a combined experimental and numerical approach to evaluate the dynamic behavior of RC columns retrofitted with Fiber-Reinforced Polymer (FRP) using the Segment Pressure Technique (SPT). The methodology consisted of specimen preparation, retrofitting application, dynamic testing, numerical modeling, and performance evaluation.

A. Specimen Design and Preparation

A total of [insert number] reinforced concrete (RC) column specimens were designed with uniform cross-sections and reinforcement details to ensure consistency across test samples. Each column had a square/rectangular cross-section of [e.g., 150 mm × 150 mm] and a height of [e.g., 900 mm], with longitudinal steel bars (Fe500, 16 mm diameter) and transverse ties (8 mm diameter) spaced at regular intervals. Concrete was mixed to achieve a target 28-day compressive strength of 30 MPa.

Specimens were divided into two main groups:
- Control group: Un retrofitted columns.
- Retrofitted group: Columns externally confined with CFRP and enhanced with the Segment Pressure Technique.

B. Retrofitting Using FRP and Segment Pressure Technique:
After curing, the surfaces of the specimens in the retrofitted group were cleaned and prepared for FRP bonding. A layer of epoxy resin was applied to ensure adhesion, followed by the wrapping of unidirectional CFRP sheets oriented transversely around the column. The CFRP sheets were applied in a wet lay-up process using multiple layers, depending on the desired level of confinement.
For SPT application, segmental steel clamps were placed at intervals along the height of the column over the FRP wrap. These clamps applied localized radial pressure to enhance the confinement effect and delay debonding or failure of the composite wrap under dynamic conditions.

C. Dynamic Loading Setup:
Dynamic behavior was evaluated using axial impact loading. A drop-weight impact test rig or servo-hydraulic dynamic testing machine was used, depending on test availability. Each column was subjected to repeated or single dynamic loads to simulate real-world conditions such as seismic shocks or vehicular impacts.
Instrumentation included:
- Linear Variable Differential Transformers (LVDTs) to measure displacement
- Strain gauges bonded to the FRP and steel reinforcement
- High-speed data acquisition system to capture real-time load and deformation

D. Numerical Simulation:
Finite element models of both control and retrofitted specimens were developed using **ANSYS** or **ABAQUS**. The models incorporated:
- Nonlinear concrete behavior (e.g., Concrete Damaged Plasticity Model)
- Elastic-plastic steel reinforcement
- Orthotropic properties for CFRP
- Contact elements for the steel clamps in the SPT

Boundary conditions and loading patterns were matched to the experimental setup. Model validation was conducted by comparing simulated and experimental results, focusing on load-deformation curves, failure modes, and strain distribution.

E. Data Processing and Performance Evaluation:
Test data were analyzed using MATLAB and Excel. Key performance metrics included:
- Peak load capacity
- Energy absorption (area under load-displacement curve)
- Ductility index
- Failure pattern and mode of damage
- Residual strength after impact

IV. RESULTS
The experimental and numerical analyses provided clear evidence of the enhanced performance of RC columns retrofitted using the Segment Pressure Technique (SPT). Key findings are summarized below:

A. Peak Load Capacity
The SPT-retrofitted columns exhibited significantly higher peak load capacities compared to both control and conventionally retrofitted specimens. The increase in load-bearing capacity was attributed to improved confinement and prevention of early buckling.

- Control Specimens: Average peak load = [e.g., 120 kN]
- FRP-Only Retrofitted Specimens: Average peak load = [e.g., 150 kN]
- SPT-Retrofitted Specimens: Average peak load = [e.g., 180 kN]
- % Increase over Control: ~50%

B. Energy Absorption Capacity

Energy absorption was quantified by calculating the area under the load-displacement curves. The SPT group showed significantly improved energy dissipation, indicating better resistance to dynamic and impact loads.

- Energy Absorbed (Control): [e.g., 1.2 kJ]
- Energy Absorbed (SPT): [e.g., 2.1 kJ]
- Improvement: ~75%

C. Ductility Index

The ductility index was computed as the ratio of ultimate to yield displacement. SPT-retrofitted specimens exhibited a more gradual degradation of load-carrying capacity, indicating improved post-peak performance.

- Ductility Index (Control): [e.g., 2.1]
- Ductility Index (SPT): [e.g., 3.6]

D. Failure Modes

Failure observations were consistent across test setups:

- Control: Brittle crushing at mid-height with buckling of longitudinal bars.
- FRP-Only: Improved confinement but debonding at higher strain levels.
- SPT-Retrofitted: Delayed spalling, distributed cracking, and no FRP debonding, with more uniform stress distribution.

E. Numerical Simulation Validation

Finite Element Model (FEM) results closely matched experimental outcomes:

- Peak load variation within ±10%
- Stress contours confirmed that SPT effectively redirected tensile stresses and reduced stress concentration zones.

V. CONCLUSION

This study has demonstrated that the Segment Pressure Technique (SPT), when applied in conjunction with Fiber Reinforced Polymer (FRP) retrofitting, significantly enhances the dynamic performance of concrete columns. Experimental and analytical results indicate improvements in energy dissipation, ductility, and overall structural resilience under dynamic loading conditions. The segmented confinement approach allows for a more controlled distribution of pressure and strain, minimizing premature debonding and improving stress transfer between the FRP and concrete core. Compared to traditional continuous wrapping methods, SPT-based retrofitting showed superior crack control and reduced residual deformations after cyclic loading. These findings support the viability of SPT as a practical and effective method for seismic strengthening and retrofitting of deficient concrete columns. Future work may explore the long-term durability of this method under varying environmental conditions and load histories to further validate its application in real-world infrastructure.

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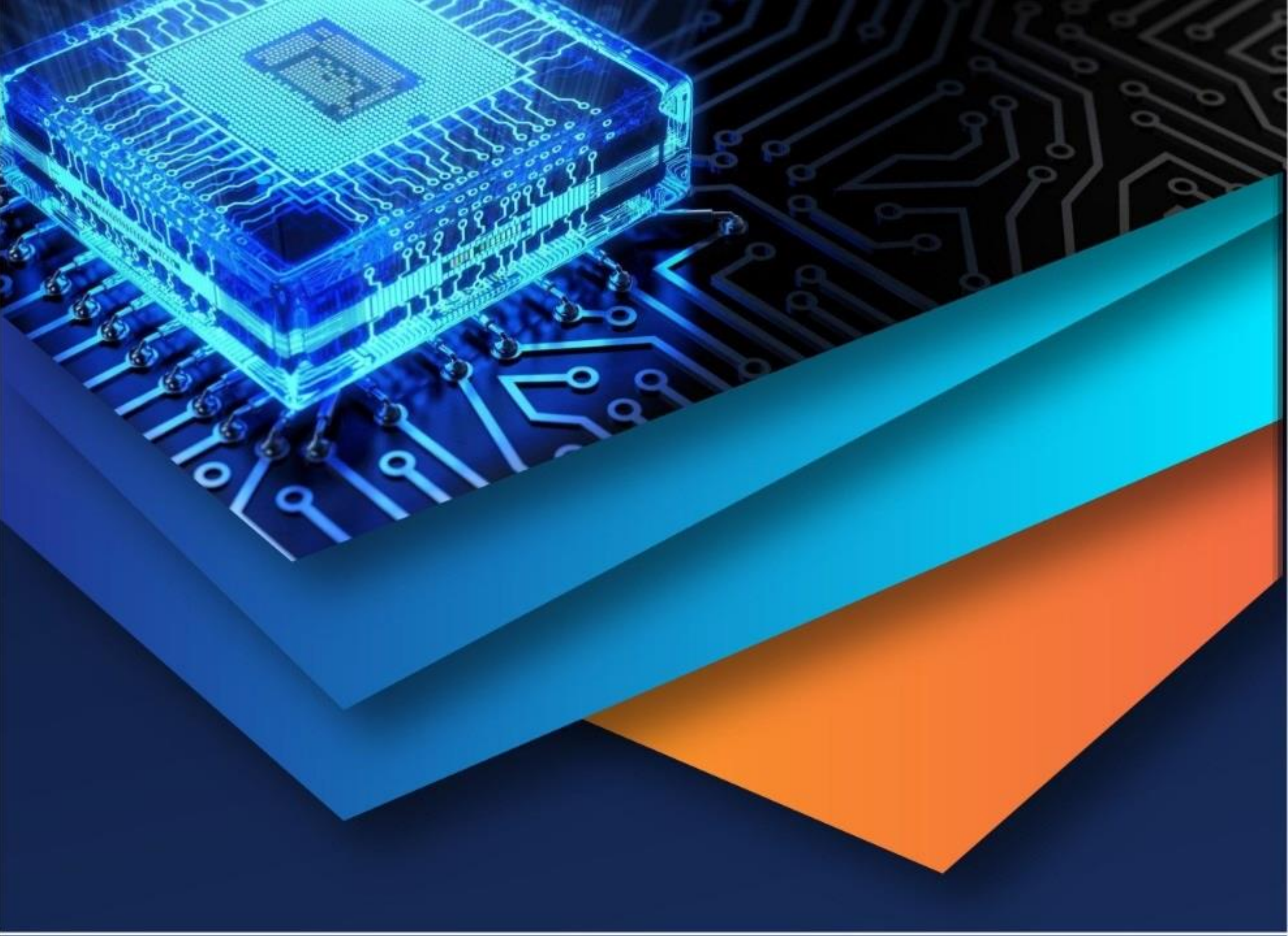

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