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Experimental Study on Load Transfer Mechanism in Columns Retrofitted by Bonding Precast Segments and FRP Wrapping

Chidanand C[1], Nikhil M Sajjan[1], Abhishek M S[1], Manoj C M[1], Manjunatha L[2,*], Bharathi Ganesh[3], Nikhil Kumar S M[4], H Sharada Bai[5]

Abstract

An experimental study was conducted to investigate the load transfer mechanism in columns retrofitted with precast segments and Fiber-Reinforced Polymer (FRP) wrapping. As the demand for structural retrofitting grows, it becomes crucial to comprehend the behavior and effectiveness of retrofit techniques to ensure the safety and integrity of existing infrastructure. The study involved subjecting a series of column specimens to axial compression loads in order to evaluate the load transfer characteristics and performance of the proposed retrofit system. Representative reinforced concrete column specimens commonly found in buildings were constructed for the experimental program. A section of these columns was retrofitted by bonding precast segments with FRP wrapping, while control specimens remained un retrofitted. The retrofitted columns underwent monotonic axial compression loads, and their behavior was compared to the control specimens to assess the retrofit technique's effectiveness. Throughout the experimental tests, various parameters such as load-displacement behavior and failure modes were monitored. Strain gauges and displacement transducers were utilized to capture internal force distribution and deformation characteristics of the retrofitted columns. The collected data facilitated a comprehensive analysis of the load transfer mechanism between the precast segments and the FRP wrapping. The retrofit system demonstrated improved load-carrying capacity, increased stiffness, and enhanced ductility compared to the un retrofitted columns. The primary governing factor of the load transfer mechanism was found to be the interaction between the FRP wrapping and the precast segments, effectively redistributing the applied loads and enhancing the overall performance of the columns.

Keywords: CFRP, micro concrete, epoxy, nito bond pc, retrofitting, column head.

***Author for Correspondence**
Manjunatha L

[1]Department of Civil Engineering, Student, Nitte Meenakshi Institute of Technology, Bengaluru, India
[1]Department of Civil Engineering, Student, Nitte Meenakshi Institute of Technology, Bengaluru, India
[1]Department of Civil Engineering, Student, Nitte Meenakshi Institute of Technology, Bengaluru, India
[1]Department of Civil Engineering, Student, Nitte Meenakshi Institute of Technology, Bengaluru, India
[1]Department of Civil Engineering Assistant Professor, Nitte Meenakshi Institute of Technology, Bengaluru, India
[2]Department of Civil Engineering, Professor, Nitte Meenakshi Institute of Technology, Bengaluru, India
[3]Department of Civil Engineering, Student, SJB Institute of Technology, Bengaluru, India
5 Professor(Rtd), Department of Civil Engineering, University Visvesvaraya College of Engineering, Bengaluru, India

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INTRODUCTION

Rehabilitation involves restoring a building or area to its former, satisfactory state, while retrofitting is the process of modifying a building to enhance its performance characteristics. When retrofitting a structure, various factors such as its intended use, safety standards, durability, ease of maintenance, and overall cost-effectiveness are carefully considered. The process includes steps like health inspections, selecting the appropriate retrofitting method, designing the retrofit structure, and executing the retrofit work in accordance with specific needs.

In circular columns, subject to axial compression, the concrete is uniformly confined by the FRP jacket. Considerable research has been conducted on the characteristics of uniformly confined concrete, resulting in numerous models that describe both compressive strength and stress-strain behavior. In contrast, our understanding of concrete behavior in FRP-confined columns with varying FRP pressure across the cross-section, where only a portion of the concrete is effectively confined, remains limited. This particular aspect has received less attention (Park and Paulay 1975).

As a result, the effectiveness of confinement is much reduced (Mirmiran et al. 1998) and rounding the right-angle corners as shown in the Figure-2. is generally recommended both to enhance confinement effectiveness and to reduce the detrimental effect of a sharp corner on the tensile rupture strength of FRP.

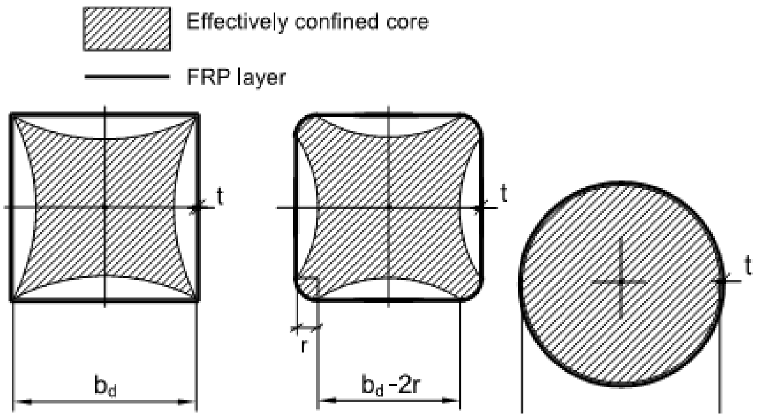

Figure 1. Effective confined concrete core of cross-section wrapped with FRP

Need For the Present Study

In upcoming method of retrofitting by shape modification using precast segments and FRP wrapping, the joint between the top of newly added pre-cast segments and beam plays a vital role in transferring the load from beams the precast segments as shown in shown in Figure 2 and 3. Hence by just attaching precast segment may not take care of this, because there may be hairline gap between the precast segments and beam. Hence development and understanding of different methods of jointing technique needs to be studied.

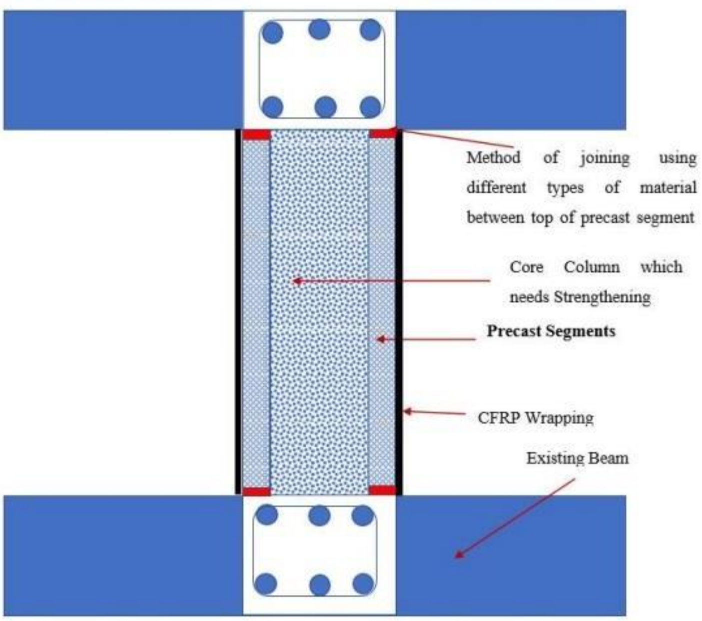

Figure 2. Methods of joining the beam and column

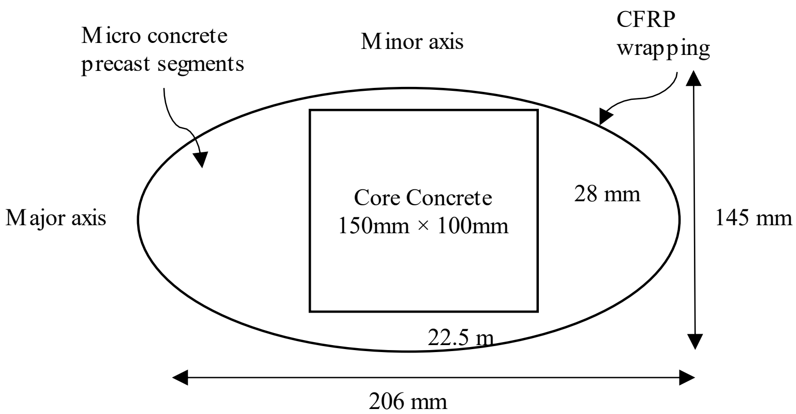

Figure 3. Present method of retrofitting

OBJECTIVES

The different objectives of present study are

1. To check the performance of joint between top of precast segment and bottom of beam in present method of retrofitting
2. To determine the load carrying capacity of columns retrofitted by precast segment and FRP wrapping in which jointing between the top of precast segment and beams done by method.

Experimental Work

Casting of Columns

The 6 number of columns with 900mm length and cross section of 100mm X 150mm (figure 4) were cast. Grade of concrete used for casting of specimens was M20. By having the properties of cement and aggregates the mix design was carried out to calculate the quantities of materials and water-cement ratio to obtain strength of 26.6 N/mm^2 (target strength). The mix proportions selected out of trial mixes are 1: 2.58: 2.48 and water cement ratio selected is 0.55.

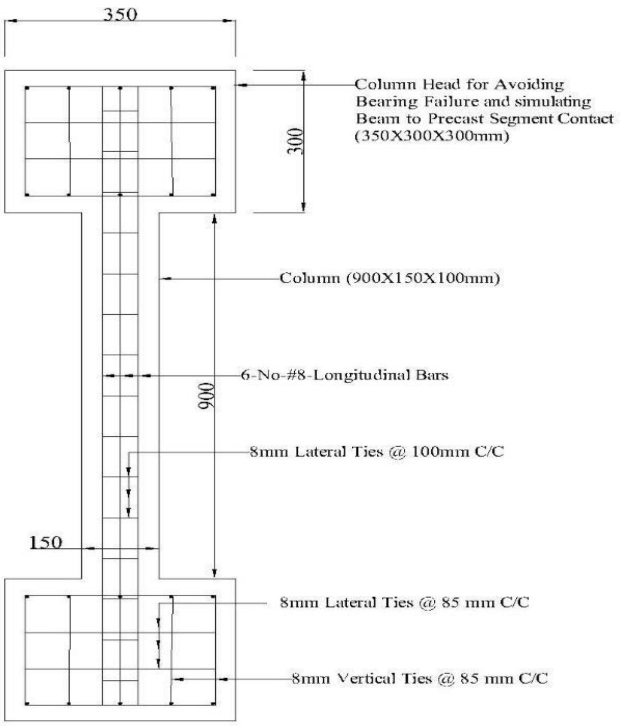

Figure 4. Section of column and column Head

Figure 5. Casting of columns

Figure 6. Cast columns

The column which is to be retrofitted is of size 150×100 mm of lengths 0.9 m. First from the ellipse shape we have deducted the area of rectangular size column and then from the remaining area of ellipse by varying the aspect ratio 3 different shapes of precast segments as shown in figure 3 are created to attach it to the column after casting Using formwork shown in Figure 7. The 3 different aspect ratios are AR 1.0, AR 1.5, AR 2.0

Figure 7. Formwork

Casting of Elliptical Precast Segments

First the retrofitting of column should be done by attaching precast segments to the column. Hence the precast segments should be casted in earlier mentioned formwork (figure 8). Mixing of micro concrete, the concrete will be mixed by hand mixing because of fast setting property of micro concrete. The mixing ratio of powder to coarse aggregates will be 1: 0.75 and water to powder ratio will be 0.16: 1 i.e. • Powder: Coarse aggregate = 1: 0.75 • Water/Powder = .160 i.e., for 1kg of micro concrete 160ml of water should be used.

Figure 8. Casting of specimen

Capping

Cementitious grouting material was used to cap the specimen at the top and bottom end faces, resulting in end surfaces that were smooth and exactly perpendicular to the longitudinal axis of the compression members after seven days. to make sure that the applied compressive stress is distributed uniformly (Figure 9 and 10).

Figure 9. Capping

Figure 10. after capping

Surface treatment of Columns and Precast segment specimens

To attach the precast segments to the columns rough surface is preferred on the sides of column and the bonding side of the precast segment. Hence the process of surface treatment or surfacing is done as shown in the figure 11 below to overcome uneven surfaces and undulation. Firstly, the column and precast specimen is made rough, then the small lines are marked in Criss cross manner so that the bonding material used to bond the precast segment to column can be applied properly.

Figure 11. Grinding of columns

Bonding Of Segmental Elliptical Concrete Covers with Rectangular Specimen

After the process of grinding all the dust particles present on the precast segment specimen and column surface should be cleaned properly because these dust particles will not allow the bonding material to bond properly. Next for attaching the precast segments, the material used is Nito bond PC 40 which hardens at slower rate compared to other grades of this epoxy.

Mixing and application of epoxy

For effective use of the epoxy material, along with epoxy hardener is also mixed with it the ratio of 3:1i.e. for 3kg of epoxy base material (white colour) and 1kg of hardener (black colour) is used. It is then mixed using putty blades uniformly until it attains uniform colour i.e light grey and make sure that no lumps are present. Epoxy is then uniformly applied to the precast segments and the column simultaneously (Figure 12). Then these precast segments are attached to the column

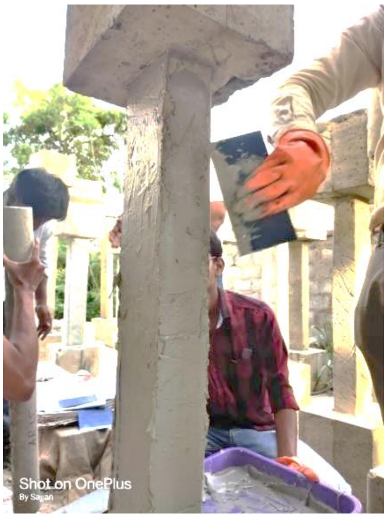

Figure 12. Applying the bond material for column

Figure 13. Applying bond material for precast

As in the present study precast segments of different aspect ratios are used, the number of sets of individual aspect ratios attached to the column are mentioned below,

- Aspect ratio 1.5: - 3columns
- Aspect ratio 1.0: - 1 columns

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- Aspect ratio 2.0: - 1 columns

Joining the Gap between Beam and Precast

At the contact places of beam and column the precast segments are cut for 10mm thickness (Figure 14). This cutting process is done because the gap between beam and precast segment attached to column can be filled easily with the epoxy material. This gap is filled with the same epoxy material with same ratios used in attaching the precast segments to the columns (Figure 15). Then this is air cured for 7days to attain the higher strength. Compared to other adhesive materials, this epoxy substance can attain superior strength. For the cube size of 70.6mm*70.6mm*70.6 mm after 7 days of air curing 124 N/mm^2 can be achieved by compressive strength test.

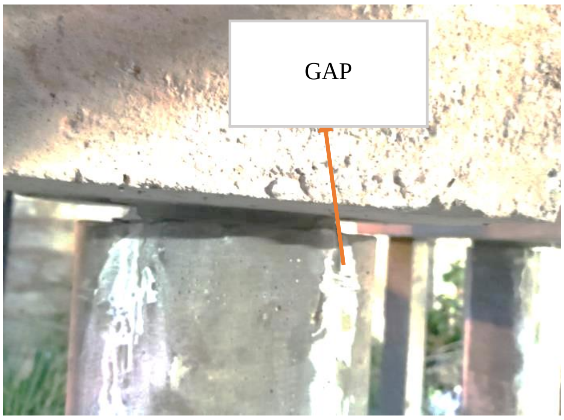

Figure 14. The Gap present between the precast segment and beam

Figure 15. Gap filling

After the placing of material there is flow of material due to viscosity and gravity to overcome this effect, we wrapped the fibre strips and binded. To wrap the Fiber Reinforced Polymer (FRP) to the column after retrofitting of column by attaching precast segments, the surface of the column should be of homogenous material as FRP and column are heterogenous, hence to make bond between them the epoxy primer is applied to column specimen in single coat or single layer and dry it for 24 hours

CFRP WRAPPING

Application of Primer

After all the grinding of undulations present on the surface of the column specimens, the epoxy primer – 330 IN is applied on the surface of The column was prepared for bonding with CFRP by manually wrapping the CFRP around the specimens. Initially, an epoxy primer was applied to the outer concrete surfaces to eliminate air voids and enhance tensile bond strength

Primer is obtained by mixing base and hardener in proportions 2.4 kg (base): 0.6 kg (hardener) by weight. Mixed primer was applied using brush as shown in Figure- 16 In case of very porous surfaces a second coat was applied. The primer was allowed to cure overnight.

Figure 16. Applying the primer

APPLICATION OF SATURANT AND CFRP SHEET

The following day, the two-part epoxy saturant was thoroughly mixed in accordance with the instructions provided by the manufacturer, and a thin coating was applied to the surface of the utilizing a bendable nylon brush. The specimen was then carefully wrapped in the CFRP laminate, with the fibers facing the direction of the hoops. Constructing CFRP in one or two layers. There was only one lap per stratum, and it was 150 mm long. In order to improve the saturant's impregnation, the air that was caught between the fiber ply and the surplus saturant was removed using a plastic deformable roller.

One final coating of epoxy saturant was added after the single-ply fiber sheet had been wrapped, and the plastic roller was once more utilized to massage the resin into the fibers. The CFRP-wrapped specimens were left overnight to cure, and the following day the same process was used to wrap the second layer of CFRP around the necessary specimens. One or two layers of CFRP were created, with each layer having a single 150 mm long lap. To ensure proper saturation and impregnation of the fibers, a pliable, deformable roller was employed to eliminate air trapped between the fiber sheet and excess saturant. Following the application of a single-ply fiber sheet, an additional layer of epoxy saturant was applied, and the plastic roller was once again employed to ensure thorough resin integration with the fibers.

Specimens wrapped with CFRP were left for curing overnight and on next day, the same procedure was followed to wrap second layer of CFRP for required specimens.

The Fiber Reinforced Polymer (FRP) is wrapped around the columns in the form of strips (Figure 17) and 18, i.e., for the length of 0.9m column, 100mm strips of FRP are wrapped around the column for the regular intervals 100mm. This will result in 5 strips of FRP for the thickness of 100mm in the column of 0.9m length. The remaining 4 strips of each 100mm gap are wrapped with brown tape Subsequently, the FRP is applied in a consistent horizontal direction around the column.

This is achieved by wrapping the brown tape around the column for the remaining 4 layers of column of 100mm thickness. This brown tape will help in proper wrapping of FRP in the uniform direction around the column. The epoxy primer material is applied around the layers of strips where the Fiber Reinforced Polymer (FRP) needs to be wrapped. Then the FRP is wrapped in the uniform manner in one-layer strips for 100mm thickness

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Figure 17. FRP wrapping **Figure 18.** Application of saturant

RESULTS AND DISCUSSIONS

General

During the destructive tests conducted on specimens the axial and lateral deformation under each increment of load, ultimate load carried and failure pattern of each specimen are recorded. The results are presented and discussed. The details of specimens are given in Tables below.

ULTIMATE LOAD CARRYING CAPACITY

Table. (1) reports the ultimate load achieved by each specimen. It is observed that ultimate load carrying capacity due to confinement of columns with CFRP wrap increased with respect to control specimen (RCS 900).

Table 1. Ultimate Loads of Specimens Tested

Specimen designation	Cross sectional area (mm^2)	No. of layers	Percentage Of FRP	Ultimate load (kN)
RCS900	15000	0	0	597
ESNF1.5-900	23554.83	0	0	1047
ESG1.5-50-1- 900	23554.83	1	50	996
ES1.5-50-1-900	23554.83	1	50	1248
ES1-50-1-900	23519.771	1	50	1222.5
ES2-50-1-900	23512.15	1	50	1417.2

By comparing unwrapped rectangular specimens' percentage increase in ultimate load and factor by which ultimate load increased is calculated and tabulated as in. Table. (Table 2 and Table 3) and Table. (3)

Table 2. Percentage Increase in Load

Specimen designation	Cross sectional area (mm^2)	No. of layers	Percentage of FRP	Ultimate Load (kN)	Percentage increase in load
RCS900	15000	0	0	597	0
ESNF1.5-900	23554.83	0	0	1047	75.37
ESG1.5-50-1-900	23554.83	1	50	996	66.83
ES1.5-50-1-900	23554.83	1	50	1248	109.04
ES1-50-1-900	23519.771	1	50	1222.5	104.77
ES2-50-1-900	23512.15	1	50	1417.2	137.38

Table 3. Factor Increase in Load

Specimen Designation	Cross Sectional Area (mm^2)	No. of Layers of	%Of FRP	Ultimate Load (kN)	Percentage Increase in Load	Factor Increase
RCS900	15000	0	0	597	0	1
ESNF1.5-900	23554.83	0	0	1047	75.37	1.754
ESG1.5-50-1- 900	23554.83	1	50	996	66.83	1.66
ES1.5-50-1- 900	23554.83	1	50	1248	109.04	2.09
ES1-50-1-900	23519.771	1	50	1222.5	104.77	2.04
ES2-50-1-900	23512.15	1	50	1417.2	137.38	2.37

From the Table. (2) to (3) it is observed that the load carrying capacity is increased with higher percentage of FRP in Elliptical Columns. The maximum percentage increase in the load carrying capacity in columns modified to elliptical shape ES2-50-1-900 the it is 137.38%, that is the ultimate load carrying capacity increased 2.37 times that of rectangular specimens Table (3). This increase is accounted due to increase in concrete area as well as CFRP wrapping.

The column ESG1.5-50-1-900 is showing increase in load carrying capacity as only 66 % whereas increase in area is 58%, this shows the premature failure of ESG1.5-50-1-900 specimen due to de-bonding precast segments and gap between the beam. From above results is clear that with increase in percentage of CFRP the load carrying capacity is increased and is more optimum for 50% increase in the FRP area.

ULTIMATE STRESSES

In below tables the ultimate stress of all specimens is listed out and percentage increase in the ultimate stress considering Rectangular unwrapped specimen.

From the above Table. (4) it is observed that the increase in the ultimate stress is more in rectangular specimen (RCS900) compared to rectangular modified to elliptical specimens' premature failure of specimens due to de-bonding and slenderness of precast segments and gap between the beam. By wrapping one layer of CFRP around the columns it is tried reduce this de-bonding and slenderness. From this is understood that one layer of CFRP is not effective. Higher number of CFRP layers may be necessary for effectively holding the precast segments and to reduce the slenderness effect.

Failure Modes

All specimens tested are short in length that is 900mm and hence buckling is not observed in any of the specimens tested. Failure is mainly due to crushing of concrete in unwrapped specimens or rupture of CFRP along with crushing of concrete in wrapped specimens.

Unwrapped specimens

Failure of all unwrapped specimens is sudden or catastrophic and brittle, with loud sound, which is a characteristic feature of Concrete.

Rectangular Specimens [Rcs900]

Failure pattern exhibited partially crushing and yielding of steel reinforcement in the one third portion from the end of the column with lateral crack as shown in Figure 19 and 20 which is loaded concentrated shows.

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Figure 19. RCS900 specimen before testing

Figure 20. RCS900 specimen after testing

CFRP WRAPPED SPECIMENS

Due to CFRP wrapping the brittle failure of column specimens is converted to ductile failure, which is essentially required in the field.

Elliptical Specimens of Aspect Ratio 2 Wrapped with CFRP

The elliptical specimen wrapped with 50% of CFRP failed at top, which was a combined process of crushing of core and micro concrete portion and tearing of CFRP fiber and at bottom there is a tear of CFRP as shown in Figure respectively.

Elliptical specimens of aspect ratio 1.5 wrapped with CFRP

The elliptical specimen wrapped with 50% of CFRP and not joining the gap between the top of precast segment and bottom of the beam failed at top, which was a combined process of crushing, debonding of micro concrete portion and tearing of CFRP fiber and at bottom there is a de-bonding of precast segment and tear of CFRP as shown in Fig respectively.

Micro Concreted Specimens [Esnf1.5-900]

Specimens failed by combination of debonding of micro-concrete portions at the interface with old concrete and crushing of elliptical segments Figure 21 and 22.

Figure 21. ESNF 1.5-900 before testing

Figure 22. ESNF1.5-900 after testing

ELLIPTICAL SPECIMENS of ASPECT RATIO 1 WRAPPED WITH CFRP

The elliptical specimen wrapped with 50% of CFRP and joining the gap between the top of precast segment and bottom of the beam and the column failed at base, which was a combined process of crushing, debonding of micro concrete portion and tearing of CFRP fiber and at bottom there is a de-bonding of precast segment and tear of CFRP as shown in Figure respectively.

SUMMARY AND CONCLUSIONS

6 columns, in which 2 unwrapped and 4 columns of different aspect ratio (AR1, AR1.5, AR2) and different percentage of FRP (0 & 50%). The unwrapped group consists of 1 rectangular (RCS900) and 5 rectangular specimens converted to elliptical by bonding elliptical segments to the rectangular specimens (ES). In this 1 is shape modification of AR1.5 aspect ratio with Gap filled with no FRP wrapped and another is shape modification of AR1.5 aspect ratio of 50% FRP wrapped and with no gap filled. Here ES represents specimens obtained using proposed innovative scheme of retrofitting the rectangular compression member by bonding elliptical segments with rectangular specimens and FRP wrapping.

Based on the limited experimental investigation carried out, the following conclusions are drawn.

i. The de-bonding of precast segments can be reduced by wrapping FRP and failure is converted to ductile failure

ii. The column modified to elliptical, and gap filled with Epoxy material is failed at higher ultimate load compared with specimen with presence of gap.

iii. Rectangular columns retrofitted by shape modification and then wrapped with CFRP show better load deformation behavior.

iv. Rectangular columns, which have undergone shape modification and subsequent CFRP wrapping, demonstrate a remarkable enhancement in their ultimate load-carrying capacity. This improvement is likely attributed to the increased cross-sectional area and the effective concrete confinement achieved through the application of CFRP wrapping.

The proposed innovative retrofitting technique considered in the present experimental investigation seems to be applicable in the field with a better and effective performance. However more studies in this regard are essential to consolidate this observation.

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