Study on Structural Retrofitting of RC Column using Carbon Fibre Reinforced Polymer

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Abstract - *Reinforced concrete columns are critical structural elements whose performance under axial compressive loading is of importance. This experimental study investigates the compressive behaviour of circular and square Reinforced concrete columns wrapped with Carbon Fibre Reinforced Polymer (CFRP) composites. CFRP wrapping is an effective retrofitting technique that enhances the strength of concrete columns. A total of 12 columns, with 6 circular and 6 squares in cross-section, were tested under axial compression load. For each shape, 3 columns were wrapped with CFRP, while 3 were left unwrapped as specimens.*

The objectives were to evaluate the influence of cross-sectional geometry and CFRP confinement on the load-carrying capacity, failure modes. Previous research has indicated that circular columns exhibit higher confinement effectiveness compared to square columns due to the continuous curvature providing more uniform confining stresses. The experimental results were critically analysed and compared with findings from relevant literature to validate this observation.

Additionally, the CFRP confinement method was compared to other retrofitting techniques, such as concrete column jacketing in terms of ease of application, cost-effectiveness, and performance enhancement.

Key Words: *Carbon Fibre Wrapping, Column, Experimental Testing, Reinforced Cement Concrete, Feasibility Study*

1.INTRODUCTION

Structural retrofitting refers to the addition and upgrade of structural components in existing buildings, bridges and infrastructure to make them safer, stronger and more resistant to forces. It enhances the load carrying capacity, stability, ductility, and service life of structures.

Conventional techniques for strengthening RC columns like concrete or steel jacketing have several drawbacks. Addition of concrete jackets increases the column size and self-weight significantly. It also requires temporary formwork support and longer construction time. Fibre-reinforced polymer (FRP) composites have emerged as an advantageous strengthening material in civil engineering applications owing to their high strength-to-weight ratio, resistance to corrosion, excellent durability and ease of application. CFRP is particularly suitable foraxial strengthening of RC columns because of its confinement nature. CFRP is a new technology which is gaining traction in India for retrofitting of structural members.

1.1 Fibre-Reinforced Polymer (FRP)

Fibre-reinforced polymer (FRP) composites have an important application in providing confinement to reinforced concrete (RC) columns, enhancing their load-carrying. This strengthening method is based on the phenomenon that the axial compressive strength and ultimate axial compressive strain of concrete can be significantly increased through lateral confinement.

Externally bonding CFRP composites onto the surface of existing RC columns through wet layup or precured laminates provides supplemental strength and stiffness. The CFRP confines the inner concrete core and enhances its compressive capacity. It also provides additional shear resistance. Moreover, the reinforcement continues to function even after concrete crushing. Many previous studies have experimentally demonstrated that CFRP wrapping significantly increases the load carrying capacity of RC columns under axial, flexural and seismic loads. However, optimization of parameters like the CFRP stiffness, thickness, orientation, and layout is critical to maximize the strengthening efficiency. Various techniques have been employed to achieve confinement of columns using FRP composites. The most common method is in-situ FRP wrapping, where unidirectional fibre sheets or woven fabric sheets are impregnated with polymeric resins and wrapped around columns in a wet lay-up process, with the main fibers oriented in the hoop direction. Additionally, filament winding and prefabricated FRP jackets have also been utilized.

This project aims to investigate structural retrofitting of RC columns using externally bonded CFRP composites. The effectiveness of CFRP retrofitting will be studied through experimental modeling of CFRP wrapped columns.

1.2. CFRP confinement in Circular and Rectangular Columns

When an FRP-confined RC column is subject to axial compression, the concrete expands laterally and this expansion is confined by the FRP. For circular columns, the concrete is subject to uniform confinement.

It has been well established that CFRP confinement is much less effective for square columns than for circular columns, even with the rounding of corners. This is because in the former, the confining pressure is non-uniformly distributed and only part of the concrete core is effectively confined. Failure generally occurs at the corners by FRP tensile rupture. The stress–strain curves are more likely to feature a descending branch, but in such cases FRP confinement normally provides little strength enhancement. The effectiveness of confinement increases as the amount of FRP or the corner radius increases, and as the aspect ratio of the section reduces.

Fig -1: Materials used for Experimentation

2. OBJECTIVES

1.) To study the effects of parameters of carbon fibre reinforced polymer composite on square and circular shape.

2.) To compare experimental failure modes with previous research data

3.) To perform cost analysis of CFRP strengthening solutions against common alternatives

3. METHODOLOGY

1.) Total 12 columns of reinforced concrete design

Were built to be tested on Universal Testing Machine (UTM). The columns were casted by using steel rebars (6mm and 8mm) and M20 grade of concrete for which 3 cubes of 150x150x150mm were tested again on UTM. 6 of the columns cast in lab were square of size 150x150x700mm and 6 were circular columns of size 150x160x700mm. Out the 6 square and circular columns, 3 of the columns were unwrapped while the remaining 3 were wrapped with CFRP of 400 microns single layer by using epoxy adhesive. The reinforcement for square and circular column were 12mm bars of main reinforcement and 8 mm bars for shear reinforcement with appropriate cover.

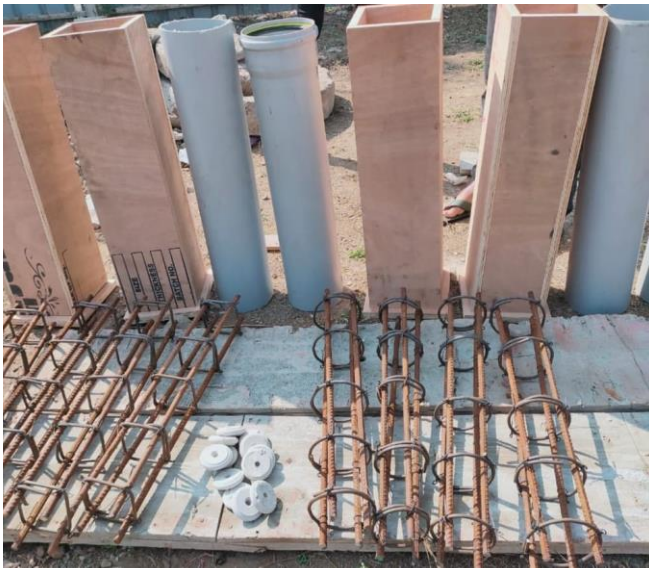

Fig -2: Circular and Square Column pre-casting

The epoxy adhesive was created by using 2 layers of Primer and Saturant of Thermax company. The primer was formed after mixing of base and hardener in proper proportion and applies over the specimens and left to dry for 24 hours. After 24 hours the saturant was formed again by mixing base and hardener of Thermax Company. Immediately after applying saturant, carbon fibre of 1 layer was wrapped around the specimens before the saturant dried up.

Mix Desnity	1.11±0.03 gm/cc
Volume of Solids	88-92%
Pot life	~25 minutes
Touch Dry Time	8-12 hours

Table-1: Properties of Primer

Mix Desnity	1.40±0.05 gm/cc
Volume of Solids	100%
Pot life	60 to 90minutes
Open Time	90 to 120 minutes

Table-2: Properties of Saturant

Fibre Orientation	Unidirectional
Weight of Fibre	400-430 gm/m2
Density of Fibre	1.80 gm/cc
Fibre Thickness	0.38-0.4 mm
Ultimate Elongation	1.7%
Tensile Strength	4000 MPa

Table-3: Properties of Maxtreat Fibrenet C400

After the application, all columns were tested to find the compressive test for them to compared the effect of shape on increase in load carrying capacity due to application of CFRP. Visual observations were made to document failure mode like concrete cracking, CFRP debonding etc.

Fig -3: Unwrapped Square Column on UTM

Fig -3: Wrapped Square and Circular Column failure after test

2.) For comparison with previous research data, peer research paper is used. Notably among the research paper selected for comparison purposes are Riad Benzaid, and Habib-Abdelhak Mesbah, "Circular and Square Concrete Columns Externally Confined by CFRP Composite: Experimental Investigation and Effective Strength Models", Fibre Reinforced Polymers - The Technology Applied for Concrete Repair, pp.167-201, 2013. The other research paper used by is Zhenyu Wang, Daiyu Wang, Dagang Lu, "Behavior of Large-Scale Circular and Square RC Columns Confined with Carbon Fiber-Reinforced Polymer under Uniaxial Compression", Advanced Materials Research Vols. 163-167, pp 3686-3693, 2010

3.) For feasibility study, it was compared to another popular method reinforced concrete column jacketing. Reinforced concrete jacketing is a method of column jacketing that involves encasing an existing concrete column with an additional layer of reinforced concrete. This technique is used to strengthen and increase the load-bearing capacity of the existing column. By adding new concrete to the previous web, the structure's dimensions are increased. Additional reinforcement could be employed to improve the structure's strength and ductility. The new reinforcement can be diagonal bars as well as vertical and horizontal bars that create the reinforcement mesh. The new reinforcement should be anchored to the foundation of the structure. Placing the reinforcement in holes drilled in the foundation and grouting it with epoxy is one method of anchoring. After solidification, the new concrete is casted with the altered proportions and cured.

3. RESULT AND DISCUSSION

1.) The testing was done after 28 days which gave the following results:-

Column Specimen	Axial Stress (Mpa)
SU1	13.73
SU2	12.53
SU3	12
SW1	18.22
SW2	16.4
SW3	16.93
CU1	8.32
CU2	7.9
CU3	8.9
CW1	15.78
CW2	16.29
CW3	16.64

Table-4: Test Results

Here, the first alphabet refers to the cross-section of the specimen, the second alphabet refers to whether the column is wrapped or unwrapped (U for unwrapped and W for wrapped), the end number refers to the specimen number.

The second columns has the axial stress for each specimen in Mega-Pascal (Mpa). Total 12 columns were tested for only axial compression to plot specimen vs axial stress chart.

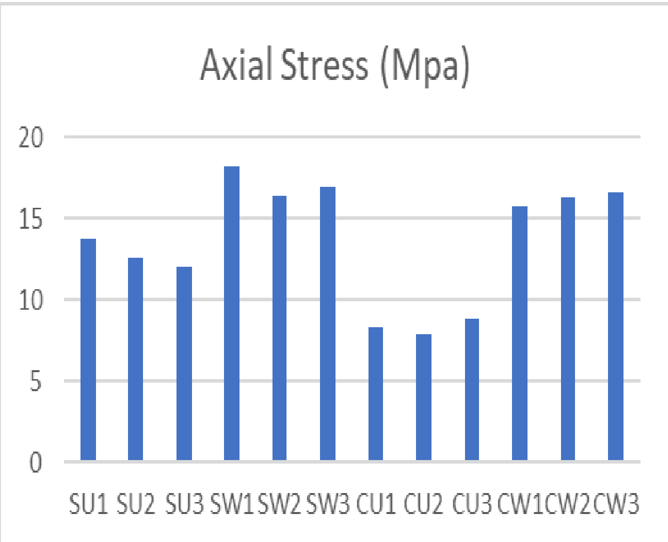

Chart-1: Test Results

On average, the axial stress for unwrapped square column is 12.75 Mpa while for wrapped square column is 17.78 Mpa. Also, for unwrapped circular column, the axial stress is 8.37 Mpa and for wrapped circular column it is 16.23 Mpa.

2.) The above results show on average an increase for circular and square columns as 93% and 34%. The highest increase seen easily for the circular columns compared to square columns as the confining is less effective for square columns due to sharp edges.

For comparison two research paper were chosen. Among one done by Riad (2013) shows an increase for circular and square sections were 69% and 22% respectively for specimens of similar nature. The specimen like our, tested showed an initial strength of 29.51 Mpa for circular column and 24.77Mpa for square column. After wrapping of one layer carbon fibre, it showed an increase of 52% for circular column and 11% for square column.

While, for the research paper done by Wang (2010), it shows for a similar size specimen with similar reinforcement structure had initial strength of 25.8 Mpa for circular column and 29.9 Mpa for square column. After one layer of wrapping, it showed an increase 100% for circular column and 18% for square column

3.) The column jacketing is extensively used in India for retrofitting of buildings as the engineers and workers are used to this method compared to FRP wrapping. If cost consideration is taken into account, concrete jacketing is cheaper than carbon fibre wrapping to gain similar strength afterwards. The carbon fibre wrapping can be as costly as 2 times the cost required for concrete jacketing due to high price of carbon fibre and high cost of epoxy resin. Also, special highly trained workers are needed for the application of CFRP due the nature of the product and its application method. As per market research, the reinforced concrete jacketing method is much more cost-effective and easier to use than CFRP wrapping in India.

It is useful to use CFRP in structures where overall maintenance time is limited and immediate recovery of strength is important such as bridges, highly deteriorated structures due to corrosion, or post-disaster structures as it takes half the time and half the labours than concrete jacketing. Also, it should be considered for maintenance of structure with historical value changing its cross-section shape or effective floor area may damage the importance of the structure. CFRP should be considered to enhance load carrying capacity of structures where Noise and Air pollution is restricted as concrete jacketing process involves usage of heavy machinery. CFRP also takes less space than concrete jacketing to achieve same strength after wrapping which increases the usefulness of CFRP. In urban area, the cost of carpet area is very high, if concrete jacketing is used to increase strength of the structural members of a building, then the carpet area is reduced quite a lot.

In our project, it took us around Rs 1500 for CFRP materials (actual carbon fibre piece + epoxy resin). If concrete jacketing was done to achieve similar strength (50% increase), then cost for it would have been half of it.

4. CONCLUSION

1.) CFRP wrapping significantly increased the strength of both circular and square columns subjected to axial compression loads. The effectiveness of CFRP wrapping varies depends on the shape of the column.

2.) CFRP wrapping on circular columns shows better results than on square columns of similar size, similar reinforcement, and similar grade of concrete due to the confining effect. The results showed that the increase in strength of reinforced concrete on average is 44% more than square shaped reinforced concrete columns.

3.) Circular columns are quite rare for both residential and business/public buildings. If there are circular columns, it is recommended to use CFRP for retrofitting rather than concrete jacketing as it increases strength substantially due to its cross-sectional shape even when the cost of CFRP is high.

For square columns, the increase in strength is quite low so for square columns if there is no issue of lowering carpet area (as in case of underground basement parking) then concrete jacketing can be used. Reinforced concrete jacketing provides excellent protection against fire, impact, moisture and chemical exposure making it suitable for columns in harsh environments.

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