IMPACT OF CORNER RADIUS AND CONFINEMENT LAYERS ON RC COLUMNS BEHAVIOR

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Abstract
Existing ferroconcrete (RC) segments could even be basically inadequate due to sort of reasons like ill-advised cross over fortification, blemishes in underlying model, lacking burden conveying limit, and so on an ineffectively bound solid segment carries on during a fragile way, prompting abrupt and cataclysmic disappointments[1,2]. Carbon/Glass(G) Fiber- fortified polymer (FRP) imprisonment are frequently successfully utilized for fortifying the inadequate RC sections. The adequacy of FRP wrapping for RC segments fundamentally relies on the corner span of the examples additionally as a spread of FRP layers utilized for the control. an endeavor has been made thus to explore the exploratory conduct of GFRP wrapped limited scope squareRC sections with fluctuating corner radii. Tentatively assessed conduct of GFRP wrapped RCsections is contrasted and the presentation noticed for non-wrapped RC segments[3,4]. Trialconduct of RC sections is additionally contrasted and scientific outcomes. 27 RC segments having cross-sectional measurements 125mm × 125mm and length of 1200mm are projected and tried under hub pressure. Three sections are un-wrapped and are assigned as control examples. Three segments each with corner radii like yet the duvet (15mm), skilled cover (25mm) and more noteworthy than the duvet (35mm), are wrapped with one and two layers of GFRP, individually. To evade an untimely break of the GFRP composite, staying six sections with a corner sweep of 5 mm are wrapped with one and two layers of GFRP, separately[5,6].

Introduction
Existing reinforced concrete columns may be structurally deficient for several reasons: substandard seismic design details, improper transverse reinforcement, flaws in structural design, and insufficient load carrying capacity. Over the last few years, there has been a worldwide increase in the use of composite materials for the rehabilitation of deficient reinforced concrete structures. One important application of this composite retrofitting technology is the use of fibre reinforced polymer (FRP) jackets or sheets to provide external confinement to reinforced concrete columns when the existing internal transverse reinforcement is inadequate[7]. Reinforced concrete columns need to be laterally confined in order to ensure large deformation under load before failure and to provide an adequate load resistance capacity. In the case of a seismic event, energy dissipation allowed by a well confined concrete core can often save lives. On the contrary, a poorly confined concrete column behaves in a brittle manner, leading to sudden and catastrophic failures. With the development of technology, the use of high-strength concrete members has proved most popular in terms of

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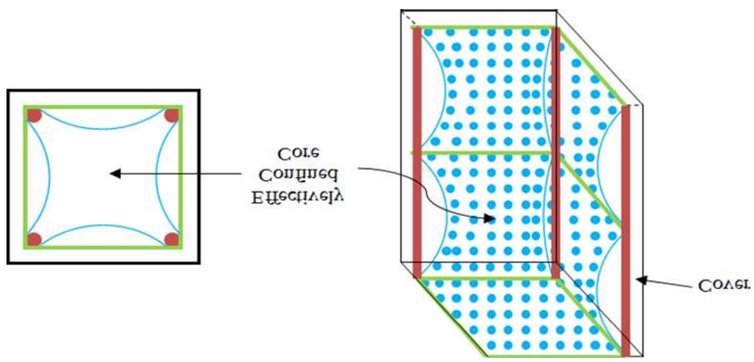
economy, superior strength, stiffness, and durability. With the increaseof concrete strength, the ultimate strength of the columns increases, but a relatively more brittlefailure occurs[8,9]. The lack of ductility of high-strength concrete results in sudden failure without warning, which is a serious drawback. Previous studies have shown that addition of compressive reinforcement and confinement will increase the ductility as well as the strength of materials effectively. Concrete, con- fined by transverse ties, develops higher strength and to a lesser degree ductility.

Behaviour of RC Columns under Axial Compressive Loading

Concrete columns when confined by suitable arrangement of transverse reinforcement show significant increase in both strength and ductility[10]. When concrete column is subjected to compression load, it undergoes volumetric changes with a lateral increase in dimension due to progressive internal fracturing and bears out against the trans verse reinforcement, which in turn exert a compressive reaction force on the concrete core. In this state the progress of internal fracturing is prevented, which in turn in- creases the strength and deformation capacityof concrete and therefore the main act of the lateral reinforcement is to produce a confined core.But as the confining action is more at the level of the ties and reduced along the length, entire core of the column do not remain effective throughout the length, Also the confining action is more at the region where there is longitudinal steel and reduced as the distance increase at the same



level as shown Figure 1. The confinement provided in the form of hoops, spiral or ties is termed as passive confinement, as the confinement comes in to action when the concrete startto increase in volume due to progressive internal fracturing and bears out against the transverse reinforcement[11,12].

Figure 1: Development of confined core in column

Objectives of Study

The main endeavor of this study is to experimentally scrutinize the effects of upgrading the load carrying capacity of reinforced concrete square columns subjected to axial compression by confining with GFRP wraps. The objectives of the study are as follows:

1) To enhance the load carrying capacity of RC column by Strengthening using GFRP wrapping.
2) To evaluate axial load, vertical deflection, lateral strain, mode of failure and crackpatterns of RC columns under axial compressive loading experimentally.

3) To evaluate the effect of the corner radius on the performance of GFRP confinedcolumns.
4) To study change in behaviour of RC columns when the corner radius is varied as 0 mm,15 mm, 25 mm & 35 mm, respectively.
5) To study change in the ultimate strength of confined concrete columns when thenumber of confinement layers are varied from 1 to 2.
6) To compare experimental results with analytical results for the RC columns[13,14].

Problem Identification

Design of RC Column as per Indian Standard

Present investigation includes a short column subjected to axial compressive load. Therefore, the column is designed based on IS 456:2000 [15] provisions to check ul- timate load carrying capacity of the member. Before evaluating the failure load of column, a check is made for its slenderness. Figure 3.1 shows cross section of the column with dimensions and direction of the application of axial load of assumed section of RC columns.

Design RC Column as per ACI Provisions

IS 456:2000 [12] does not cover any provisions pertaining to design of FRP wrapped columns. The FRP wrapped columns are designed using provisions of ACI 440.2R - 08 [14]. However to maintain adequate correlation, the control columns are further designed[16] based on provisionsof ACI 318M - 08 [13]. Parameters of assumed section of RC columns are as given in Table 3.1.

For short axially loaded column,

$= 0.80[0.85 f^{j}(Ag - Ast) + f yAst]$

= 0.80 [0.85 ×(0.8 × 20.57) × (15625 - 201.06)] + (415 × 201.06)

= 239.34 kN

Where,

A_g = Gross area of concrete section

A_{st} = Total area of non prestressed longitudinal reinforcement (Assumed 4 - 8mm φ)

Note: $f^J = 0.8 \times f_{cube}$

= 0.8 × 20.57 [Table 4.2]

= 16.46 N/mm^2

Design of RC Column Strengthened with GFRP Wrapping

It is desired to design an FRP wrapping for RC column of square section, in order to evaluate increase in load bearing capacity due to the wrapping[17]. Before application of the wrapping, in order to avoid concentration of stresses at the corners, they have been rounded with various radii as shown in Figure 3.3. Following different corner radii have been considered:

- 0 mm Corner radius (Sharp edges)
- 15 mm Corner radius (Less than cover of 25 mm)
- 25 mm Corner radius (Equal to cover of 25 mm)
- 35mm Corner radius (More than cover of 25 mm)

Experimental Work

Castings of all columns are conducted by using M15 concrete grade mix. Mix design of M15 concrete has been made. Concrete mix proportion selected as Water : Cement: Sand : Coarse Aggregates, 0.60 : 1 : 3.25 : 5. Proportion of ingredients used for $1m^3$ concrete mix are shown Table 4.1. Table 4.2 shows average cube strength of 3 cubes after 28 day of curing period which was taken at the time of casting of specimens. Therefore, the average value of cube compressive strength of concrete is 20.57 N/mm^2 and also has been used in analytical computations in chapter 3 whenever required.

Table - 1: Proportions of ingredients used for concrete mix (1m^3)

Ingredients	Quantity
Cement	270 kg/m^3
Sand	877.5 kg/m^3
10 mm aggregate	945 kg/m^3
20 mm aggregate	405 kg/m^3
Free water	162 kg/m^3

GFRP Sheet

The glass-fiber sheets used in present investigation were a unidirectional wrap. The properties of GFRP sheet are presented in Table 2. The resin system that is used to bond the glass fabrics over the columns is an epoxy resin made of two-parts, resin and hardener[18,19].

Table -2 : GFRP Properties Supplied by Manufacturer

Fiber Weight (g/m^2)	Sheet Width (mm)	Fiber Thickness (mm)	Ultimate tensile strength (MPa)	Elastic modulus (MPa)	Ultimate elongation εfu (%)
900	500	0.324	3400	74500	4.3

Formwork

Formwork plays very important role to maintain correct shape of the column and to achieve proper surface finishing. To avoid the problem of segregation and honey- combing in concrete, casting of the column is conducted by keeping the specimen in horizontal direction.

Formwork with Sharpe Edges for Square Column

Formwork for the square columns has been prepared using 19 mm waterproof plywood sheets cut and assembled to provide 90˚ corners with a plywood formed bottom. The formwork is cut and assembled very carefully to ensure accurate vertical sid
es and 90˚ verticality for corners. Internal dimension of the formwork is 125 × 125 × 1200 mm.

Figure 1 shows schematic view with dimensions of formwork. Figure 4.4 shows the competed formwork.

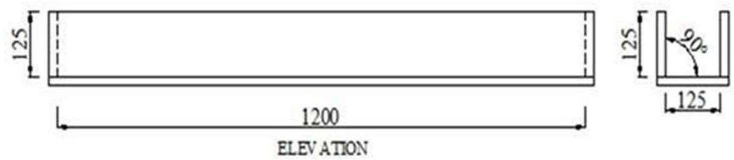


Figure 1: Schematic view of formwork with sharp edges

Figure 2: Completed formwork with sharp edge

The specimens are tested on loading frame under axial compressive loading. The axial load is applied through hydraulic jack of 2000 kN capacity and the capacity of the frame is 1000 kN. General arrangement of test setup is shown in Figure 4.18.

The columns are placed with hinged supports on either side. The load is applied from the bottom of column through hydraulic jack. Load is transferred from jack to supporting plate to column and finally on the loading frame through ground.

Results & Discussion

This paper deals with reporting of test results like: Axial compressive load, displacement and strain for control and wrapped column with various corner radii. Load is increased on the column at specific intervals and corresponding to every load dis- placement and lateral strains are measured for the columns. Comparison of Ultimate failure load, maximum displacement, lateral strain and axial strain evaluated at different positions for both categories of columns is presented in tabular as well as in graphical form. These parameters are very essential to understand the behavior of control and GFRP wrapped columns. Different parameters discussed in this chapter for RC columns are as follows:

- Ultimate failure load
- Load vs. displacement
- Axial stress vs. strain
- Corner radius effect
- Failure modes
- Comparison of experimental and analytical results

Notations for Columns

Following notations have been used during reporting of all results in this chapter:S0R0 = Control column

S1R0 = One layer of GFRP sheet for column having 5 mm corner radius S2R0 = Two layers of GFRP sheet for column having 5 mm corner radius S1R1 = One layer of GFRP sheet for column having 15 mm corner radius S2R1 = Two layers of GFRP sheet for column having 15 mm corner radiusS1R2 = One layer of GFRP sheet for column having 25 mm corner radius S2R2 = Two layers of GFRP sheet for column having 25 mm corner radiusS1R3 = One layer of GFRP sheet for column having 35 mm corner radius S2R3 = Two layers of GFRP sheet for column having 35 mm corner radius

Comparison of ultimate failure load keeping corner radius constant

Comparison of ultimate failure load for column specimens keeping corner radius constant. Figure 5.1 shows comparison between S0R0, S1R0 and S2R0,respectively. Here the corner keeping R0 has been kept constant and the numbers of FRP layersare varied as to single wrap and double wrap. Increase in ultimate load carrying capacity of 47.25 % and 96.70 % has been observed for columns S1R0 and S2R0 as compared to that for column S0R0, respectively.

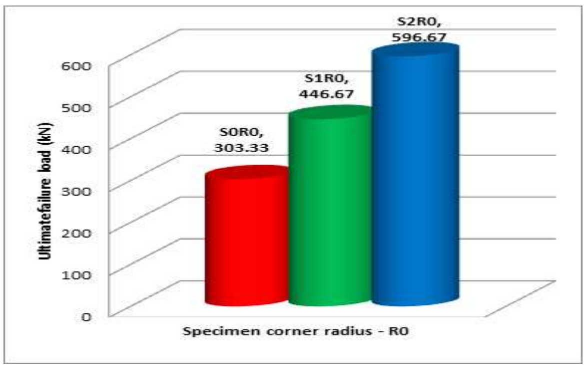


Figure 3 : R0 columns with corner radius

Figure 3 shows the comparison between S1R1 and S2R1 keeping corner radius R1 constant. Comparing S1R1 to S2R1 the value of ultimate load carrying capacity in- creased with 43.84 % for specimen S2R1.

In Analytical calculation the formula φP_n for calculating axial load in confined condition, contains reduction factor, $\varphi = 0.70$ that reduce the axial load carrying capacity. Therefore analytical results are conservative and showing less value than experimental results.

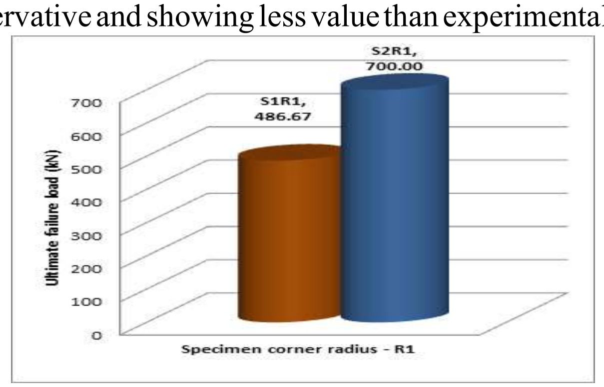


Figure 4 : R1 columns with corner radius

Conclusions

A total of 27 RC columns are tested under axial loading. Three columns are un- wrapped and have been designated as control specimens. Three columns each with corner radius equivalent to less than cover, equal to cover, greater than cover, are GFRP wrapped with one and two layers, respectively. The main purpose is to in- vestigate the effect of corner radius on the effective confinement that is provided by GFRP sheet for RC columns. The test variables included the different corner radius and number of GFRP layers. The values of Ultimate failure load, displacement and lateral strain of columns are recorded. The test results indicate that corner radius is of great importance in relation to the level of confinement. Experimental test results are compared with value calculated from the IS 456: 2000, ACI 318M - 08 andACI 440.2R - 08 code provisions.

Based on the analysis of experimental results and the performed analytical verification, the following conclusions can be drawn:

- The experimental results clearly demonstrate that GFRP wrapping can enhance the structural performance of RC columns under axial loading,[22,23] in terms of both maximumstrength and strain.
- Amongst all retrofitting techniques wrapping technique increasing axial strength by providing addition confinement without increasing the size.
- Percentage increment in ultimate failure load is ranging from 8.10 % to 149.45 % for all wrapped columns as compared to that of control columns.

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