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Experimental Study on External Strengthening of RC Columns using CFRP Composites

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Abstract : The use of Carbon fiber reinforced polymer (CFRP) materials for structural repair and strengthening has continuously increased in recent years, due to several advantages associated with these composites when compared to conventional materials like steel. This paper presents the results of an experiment at study on the structural behavior of reinforced concrete columns strengthened with carbon fiber sheets and strips in pre-cut grooves. The reinforced columns were strengthened before testing. The main tasks of these experiments were conducted to investigate the effects of additional strengthening of reinforced columns.
Keywords : Carbon Fibre Reinforced Polymer, CFRP strengthened concrete columns, strengthening, confined concrete, buckling strength.

Introduction

In recent decades the existing columns are undergoing retrofitting and which has become an indispensable requirement. To strengthen these existing reinforced concrete columns the application of Carbon Fiber Reinforced Polymers (CFRPs) has been done. The strength and stability were found to be increased invariably using these CFRP, of the strengthened columns. Both the experimental studies and theoretical studies on behavior of concrete confined with CFRPs showed the stress-strain behaviors for CFRP confined concrete, especially the circular columns under concentric loadings. It was evident based on the theoretical and experimental results, that, the CFRP confinement of a circular column was greater than that compared to square column. In case of square columns, the efficiency of CFRP confinement was less because, the stresses were concentrated at the corners and the active area of the confined section by CFRP was low. Hence, it was noticed that modifying a square column to a circular one will definitely increase the effectiveness of CFRP confinement. Most of the existing columns are square or rectangular in cross sections as these are easy to construct by regular square and rectangular formwork, compared to circular columns. However, early investigations indicated that the CFRP confinement for square or rectangular columns with sharp corners provided very little enhancement in their load carrying capacity, while confinement effectiveness increases linearly with an increase in the corner radius. Despite, the curvature of the corners could cause stress concentration. Therefore, modifying a square column to a circular column may minimize the stress concentration became an objective of this study. Existing structures sometimes requires retrofitting in cases involving change of the use of the structures, change of design codes and construction errors. Since most structures are constructed with normal strength concrete, the experiments of this study imitate that by utilizing normal strength concrete. This study investigates the technique of modifying the cross section by circularizing RC square column to circle.

Experimental Program

In recent decades the existing columns are undergoing retrofitting and which has become an indispensable requirement. To strengthen these existing reinforced concrete columns the application of Carbon Fiber Reinforced Polymers (CFRPs) has been done. The strength and stability were found to be increased invariably using these CFRP, of the strengthened columns. Both the experimental studies and theoretical studies on behavior of concrete confined with CFRPs showed the stress-strain behaviors for CFRP confined concrete, especially the circular columns under concentric loadings. It was evident based on the theoretical and experimental results, that, the CFRP confinement of a circular column was greater than that compared to square column. In case of square columns, the efficiency of CFRP confinement was less because, the stresses were concentrated at the corners and the active area of the confined section by CFRP was low. Hence, it was noticed that modifying a square column to a circular one will definitely increase the effectiveness of CFRP confinement. Most of the existing columns are square or rectangular in cross sections as these are easy to construct by regular square and rectangular formwork, compared to circular columns. However, early investigations indicated that the CFRP confinement for square or rectangular columns with sharp corners provided very little enhancement in their load carrying capacity, while confinement effectiveness increases linearly with an increase in the corner radius. Despite, the curvature of the corners could cause stress concentration. Therefore, modifying a square column to a circular column may minimize the stress concentration became an objective of this study. Existing structures sometimes requires retrofitting in cases involving change of the use of the structures, change of design codes and construction errors. Since most structures are constructed with normal strength concrete, the experiments of this study imitate that by utilizing normal strength concrete. This study investigates the technique of modifying the cross section by circularizing RC square column to circle.

Test Methods

CFRP were bonded to the columns after carrying out the surface preparation. All the surfaces of the Columns were made smooth using a rotary grinder. It is important to make the top and bottom surfaces of columns exactly flat to apply uniform load on both surfaces. Then the saturated CFRP layers with epoxy were pasted on to the column surfaces.

Fig 3.Fully and partially fibre wrapped test specimens

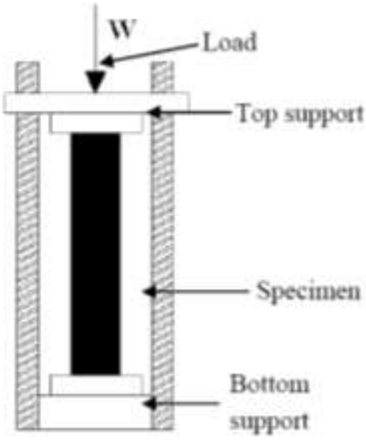

Fig 4. Loading arrangement

Loading arrangement and experimental setup

The loading arrangement and the experimental setup are shown in figures. Columns were tested using Amsler testing machine with 200 ton capacity under a pure axial compression loading.

To monitor the behavior of columns under loading, two strain gauges and two LVDTs (Linear Variable Deformation Transducers) and one dial gauge were placed accordingly to measure the vertical and lateral strain and vertical and lateral deformation of the columns.

Fig 5. Testing of column

Fig 6. Failure mode of conventional column specimen

Fig 7. Testing of CFRP confined column specimen

Fig 8. Failure mode of CFRP confined column specimen

Results

Table 4. Load-Displacement - Control Beam

Load (kN)	Displacement (mm)
0.0	2.4
0.5	5.8
1.0	10.25
1.5	23.50
2.0	45.25
2.5	74.15
3.0	106.25
3.5	143.35
4.0	182.15
4.5	218.15
5.0	254.12
5.5	290.15

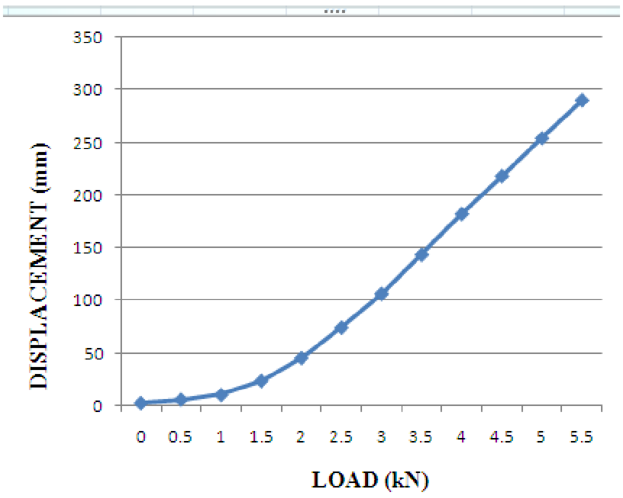

Fig 10. Load-Displacement - Control Beam

Table 5. Load-DisplacementPWB-Single Layer

Load (kN)	Displacement (mm)
0.0	1.75
0.5	4.92
1.0	10.15
1.5	29.12
2.0	50.17
2.5	71.26
3.0	86.15
3.5	111.15
4.0	140.15
4.5	166.25
5.0	187.15
5.5	207.15
6.0	216.16
6.5	232.45
7.0	256.15
7.5	276.32
8.0	289.15

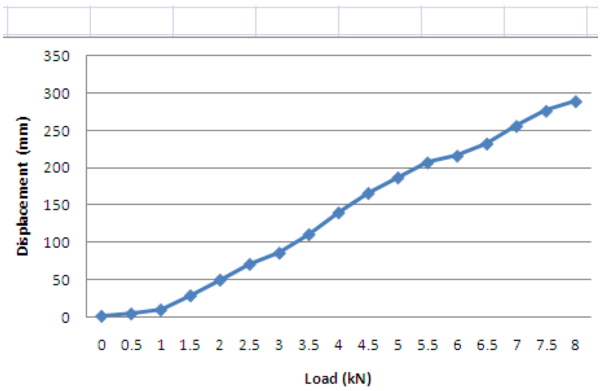

Fig 11. Load-Displacement - PWB-Single Layer

Table 6. Load-Displacement - PWB-two Layer

Load (kN)	Displacement (mm)
0.0	2.35
0.5	4.46
1.0	7.47
1.5	14.25
2.0	26.12
2.5	40.15
3.0	55.16
3.5	80.12
4.0	104.15
4.5	126.56
5.0	162.42
5.5	204.15
6.0	244.25
6.5	286.15
7.0	305.15
7.5	332.15
8.0	349.15
8.5	370.15
9.0	383.12
9.5	401.15

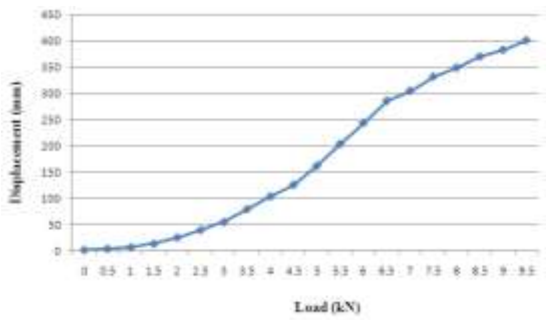

Fig 11. Load-Displacement - PWB-Two Layer

Table 7. Load-Displacement - FWB-Single Layer

Load (kN)	Displacement (mm)
0.0	2.85
0.5	6.92
1.0	18.15
1.5	35.16
2.0	57.35
2.5	76.12
3.0	95.16
3.5	123.14
4.0	153.15
4.5	167.15
5.0	185.12
5.5	219.25
6.0	241.16
6.5	263.15
7.0	273.15

7.5	292.12
8.0	308.25
8.5	309.16
9.0	330.15

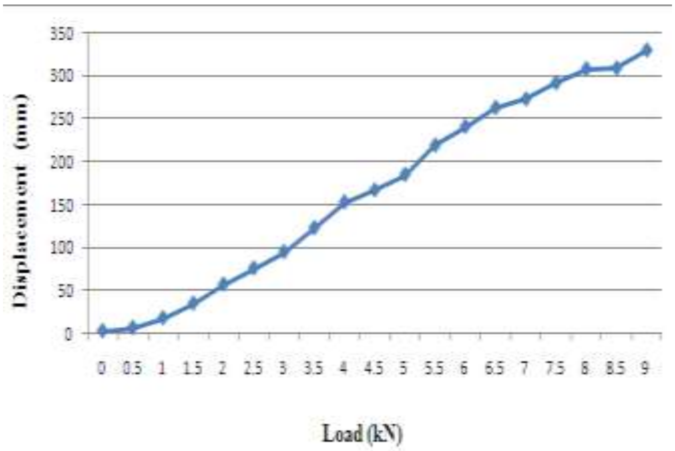

Fig 12. Load-Displacement - FWB-Single Layer

Table 8. Load-Displacement - FWB-Double Layer

Load (kN)	**Displacement (mm)**
0.0	2.65
0.5	7.40
1.0	14.15
1.5	26.12
2.0	40.15
2.5	60.26
3.0	93.15
3.5	134.16
4.0	154.25
4.5	178.15
5.0	206.15
5.5	229.12
6.0	249.15
6.5	265.16
7.0	289.15
7.5	304.15
8.0	321.15
8.5	336.15
9.0	350.23
9.5	367.38
10.0	382.15
10.5	396.26
11.0	407.12
11.5	418.25
12.0	426.85
12.5	438.15

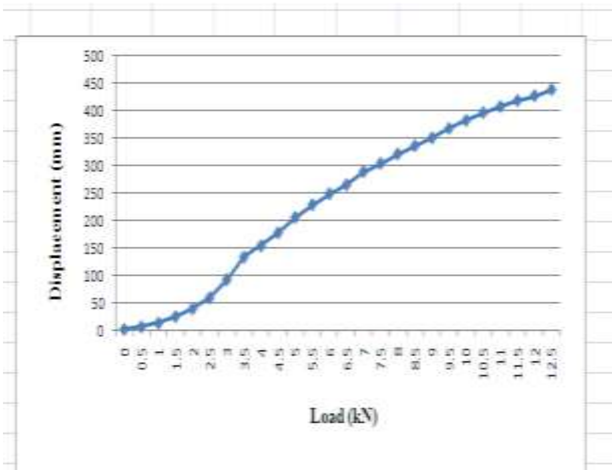

Fig 13. Load-Displacement - FWB-Double Layer

Conclusion

An experimental study was undertaken to investigate the behavior of realistically sized RC columns strengthened with externally bonded CFRP and subjected to a loading. Two strengthening configurations were tested: columns combining CFRP confinement with flexural reinforcement achieved by bonded longitudinal CFRP plates. The specimens were tested under constant axial load simulating gravity load. First, usual trends were confirmed:

- better performances, in terms of ductility, are observed for confined columns compared to reference specimens,

But, within the limits of this study, the following original conclusion has also been drawn:

- longitudinal reinforcement, applied in addition to confinement, does not noticeably change the behavior of the columns in terms of ductility, strength, or dissipated energy (compared to simply confined column) and are then considered ineffective.

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