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Behaviour of FRP strengthened concrete columns under eccentric compression loading

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Behaviour of FRP Strengthened Concrete Columns under Eccentric Compression Loading

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ABSTRACT: This paper presents results of testing eccentrically loaded columns externally wrapped with two types of materials. Six cylindrical (205 mm diameter and 925 mm height) plain columns were cast and tested. Half of the columns were wrapped with GFRP and the other half with CFRP. All columns were tested by applying an axial load at 50 mm eccentricity. In each group (GFRP or CFRP wrapped) of columns, one column did not have any vertical straps, one had vertical straps made of one layer of wrapping material and one column had vertical straps made of three layers of materials. All columns were horizontally wrapped with three layers of material (GFRP or CFRP). A steel reinforced column was also cast and tested to serve as a reference column. Based on testing the columns it can be concluded that considerable gain in strength and ductility are gained when reinforcing the columns with CFRP (vertical straps and horizontally wrapped).

Keywords: FRP, RC Columns, Eccentric loads, Vertical straps

INTRODUCTION

The effectiveness of wrapping concrete elements, for example beams and columns have been proven by several researchers, for example: [1-3]. Several studies have reported on testing reinforced concrete columns wrapped with different types of FRP. With the exception of a few studies for example: [4-6], most are based on testing columns under concentric loads. It is clear that there is a need to investigate the behaviour of columns under eccentric loads as most of the columns in buildings, especially at the edge and corner are subject to uniaxial or biaxial loading.

Several studies have reported on the behaviour of reinforced concrete columns wrapped with FRP. This paper investigates the behaviour of plain concrete columns. Vertical FRP straps are applied on the column. Then FRP is used to wrap the columns circumferentially. All columns are tested to failure by applying an axial compressive eccentric loads. Results of testing the columns showed that FRP straps are effective in producing columns with higher capacity and ductility compared with reinforced concrete columns.

EXPERIMENTAL PROGRAMME

A total of seven columns were cast and tested. All columns had a height of 925 mm and a diameter of 205 mm. One column (Column R) served as a reference column and was reinforced longitudinally with 6N12 steel bars (12 mm deformed bars with 500 MPa nominal tensile strength). Helices were provided with 10 mm plain bars (250 MPa nominal tensile strength) at 60 mm pitch. The remaining six columns were made of plain concrete then vertical FRP straps were added, followed by wrapping the columns horizontally with FRP. Three of the six plain columns were wrapped with GFRP. Column G0 had no vertical straps, Column G1 had one layered vertical strap and Column G3 had three layered straps. All the three columns were horizontally wrapped with three layers of GFRP. Columns C0, C1 and C3 were also made of plain concrete and were wrapped similar to Columns G0, G1 and G3 but were wrapped with CFRP rather than GFRP.

The vertical straps were made of 50 mm FRP (GFRP or CFRP) and were glued to the columns at an equal spacing of 57.5 mm. Figure 1 shows a schematic plan view of the vertically reinforced columns and Table 1 shows the dimensions and reinforcement of all the columns.

Preliminary Tests

The concrete of the columns was supplied by a local supplier and had an average compressive strength at 28 days of 65 MPa. Four specimens of the reinforcing steel were tested to determine their tensile strength. The tests revealed that the bars had an average tensile strength of 615 MPa.

Tensile strength tests were carried to determine the properties of FRP. These were achieved by testing coupon samples. Table 2 shows the results of testing the FRP.

Preparing Test Specimens

The first stage of specimen construction was to prepare the circular PVC tubes. Seven formworks were used in the experiment. In order to maintain a perfect environment for concrete columns, high pressure air was first used to clean the wooden platform. Then, the PVC tubes were fixed straight up on the wooden platform and were tested to make sure the tubes were level. Because those formworks were easily moved when placing the reinforcement and concrete, four vertically steel straps and three circular steel straps were placed on the surface to stabilise them.

One reinforcement cage was tied for Column R and then put into the formwork, then steel cages were used at the bottom of the reinforcement to ensure a 22.5 mm clearance. In order to stabilise the reinforcement straight in the formwork, six steel bars were welded on the side of reinforcement. Next, the reinforcement cage was placed into the formwork (as shown in Figure 2) and oil was sprayed inside of formwork in order to easily remove it from the concrete.

High strength ready mixed concrete was used. A slump test gave a reading of 120 mm. In the curing period, the concrete columns were covered by moist Hessian in order to give a suitable

humidity. Seven days was required for the concrete to cure before removing the formwork. The specimens were placed on a wooden bench and covered by moist Hessian to obtain further curing. After fourteen days curing, the concrete columns were ready for wrapping with FRP-reinforcement.

Construction of FRP-confinement

Two different types of FRP were used during the perpetration of the columns. Uni-directional Carbon Fibre 75 mm wide tape or plain weave E-Glass fibre 75 mm wide tape. For Columns G0 and C0, first the columns were cleaned and completely dried then an epoxy resin and hardener mixture of 5:1 was used as the gluing agent for the FRP. The resin mixture was initially applied to the concrete with the FRP tape wrapped around the column to produce a total cover of the column. The first FRP layer was then covered in the resin mixture with a second layer of FRP wrapped around the column. This procedure was repeated again for a third layer with a final coat of resin mixture applied over the third layer to seal the FRP. The columns were then left for 24 hours to allow the resin mixture to set and harden.

The columns containing the vertical straps were wrapped slightly different to those only wrapped with FRP. The position of the vertical straps was marked. A resin and hardener mixture was then applied to the area of the straps. The FRP straps were then placed on the resin mixture. Another layer of the resin mixture was then applied and the process continued. Once all the vertical straps were applied to the column the entire column was covered with the resin mixture and then wrapped with three layers of the same FRP used for the straps. Taking care to ensure the FRP adequately attached to the column regions between the vertical straps.

Column Test

The apparatus used to apply the load was a Denison 500t located in the Engineering Laboratory of the University of Wollongong. Firstly, in order to level the column end so that a uniformly distributed force could be applied to the entire face, high strength plaster was mixed, and poured into the top steel plate. A curing time of 30 minutes was imposed to wait for the strength of plaster to become strong enough to hold the steel plate and column together. Then, the column was turned around and lifted up to transport to the testing machine. The high strength plaster was mixed again and poured into the bottom steel plate. The column was placed on the bottom steel plate and a small load was applied on the column in order to make it straight. After the high strength plaster was cured and enough strength gained to hold the column and steel plate together, the column was lifted up and eccentric loading plates (Figure 3) were set up.

The axial deflection of the columns was measured by a Laser Deflection Gauge placed on a corner of the platform and connected to StrainSmart system, which was installed on a computer. The lateral deflection of the columns was measured by a LVDT placed in the middle of the column and connected to computer.

TEST RESULTS

All seven columns were tested under an axial compressive load with a 50 mm eccentricity. A rigid 500 tonne compression machine was used to apply the load. Especially designed column heads were used to apply the eccentric load. All results were captured electronically and stored in a computer. Table 3 presents a summary of the test results.

Figure 4 shows the behaviour of the two columns without any vertical straps, but with the horizontal wrapping only, i.e Columns G0 and C0. Column R is also added for comparison

purposes. As shown in Figure 4, although Column C0 is made of plain concrete and only horizontally wrapped with three layers of CFRP, it showed better properties both in strength and ductility than the reference column, Column R.

In order to investigate the effectiveness of the straps, Figures 5 and 6 were plotted. Figure 5 shows the behaviour of Columns G1 and C1. The behaviour of Column R is added as a reference. Similarly Figure 6 shows the behaviour of Columns R, G3 and C3. From Figure 5 it is clear that Column C1 outperformed both Column G1 and Column R. Similarly, Figure 6 shows that Column C3 outperformed both Column G3 and Column R.

In order to explore the effectiveness of the FRP straps, Figures 7 and 8 were plotted. Figure 7 shows the behaviour of the reference column, together with Columns G0, G1 and G3, with no straps, one layered straps and three layered straps were applied to the columns, respectively. Similarly Figure 8 shows the behaviour of Columns R, C0, C1 and C3. It is obvious the higher number of FRP layers in the vertical straps gave better performance.

DUCTILITY

The area under the load-axial deflection curves for each column was calculated and are presented in Table 4. These values can correlate to the ductility of the columns. It is clear from Table 4 that the columns which were vertically strapped with CFRP performed far better than the steel reinforced reference column.

CONCLUSIONS

The use of steel reinforcement in concrete construction has proven to be very effective due to the excellent properties that the reinforcing steel has that compliment the concrete properties, for example increase in tensile strength and ductility. However, one of the drawbacks of steel is its long-term behaviour especially in areas where the humidity is high. In such areas, the steel usually suffers from rust and oxidation which eventually lead to the deterioration of the concrete structure. One method to reduce this effect is to protect the reinforcing bars, for example wrapping or using cathodic protection. This paper investigates the behaviour of plain concrete columns reinforced with FRP both in the vertical and horizontal directions.

As most columns are subject to a combination of axial and bending forces, the experimental programme presented in this paper is for columns that are eccentrically loaded. A total of seven columns were cast and tested. The load-deflection (both axial and lateral) curves are presented in this paper.

Based on the experimental programme of this study, the following conclusions are drawn:

i. Columns made of plain concrete and vertically reinforced with CFRP as well as being wrapped by CFRP performed better than the reference column which was reinforced with steel. The better performance applies both for strength and ductility.

ii. The performance of the GFRP wrapped columns was slightly better than the reference columns.

iii. Although being tested under eccentric loads, the CFRP columns outperformed both the GFRP and the steel reinforced columns.

iv. The concrete used in the current study had a compressive strength of 65 MPa. Further research is required to cover more strengths of concrete before a generalisation of the findings can be achieved.

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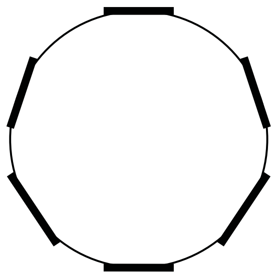

Figure 1 – Schematic plan view of the vertically reinforced columns.

Figure 2 – Placement of Reinforcement into formwork.

Figure 3 – Eccentric loading plate and steel plate

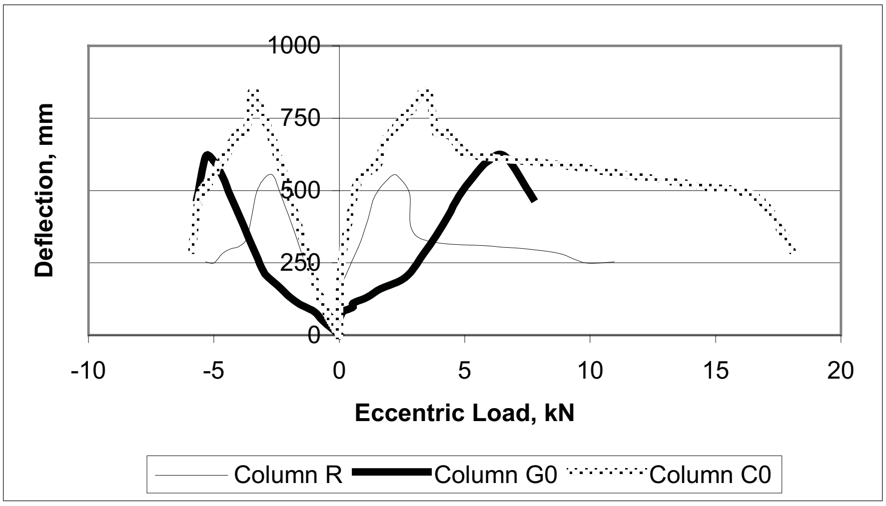

Figure – 4 Load-deflection curves for Columns R, G0 and C0

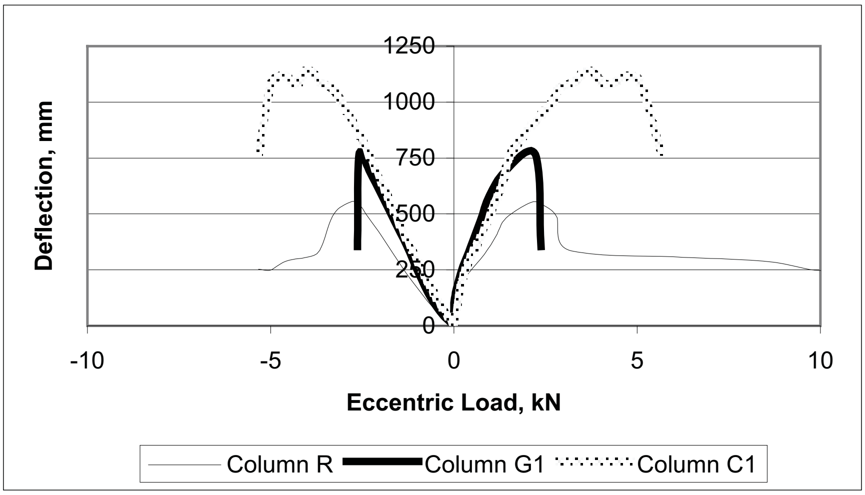

Figure – 5 Load-deflection curves for Columns R, G1 and C1

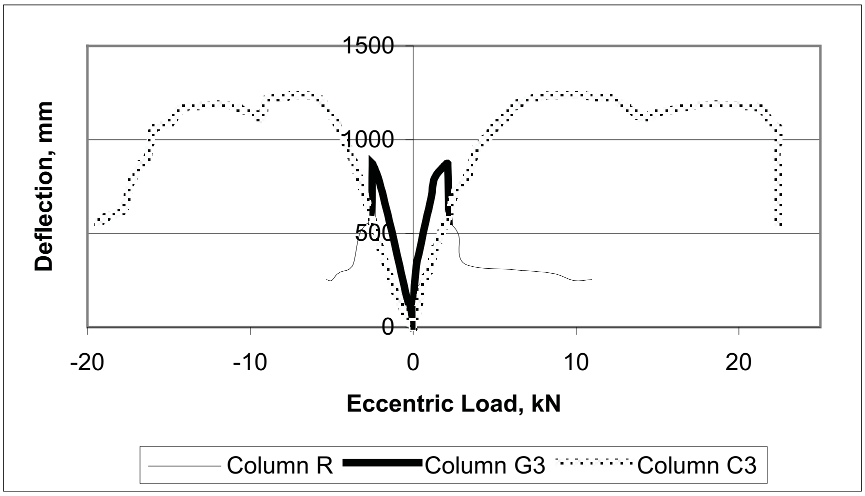

Figure – 6 Load-deflection curves for Columns R, G3 and C3

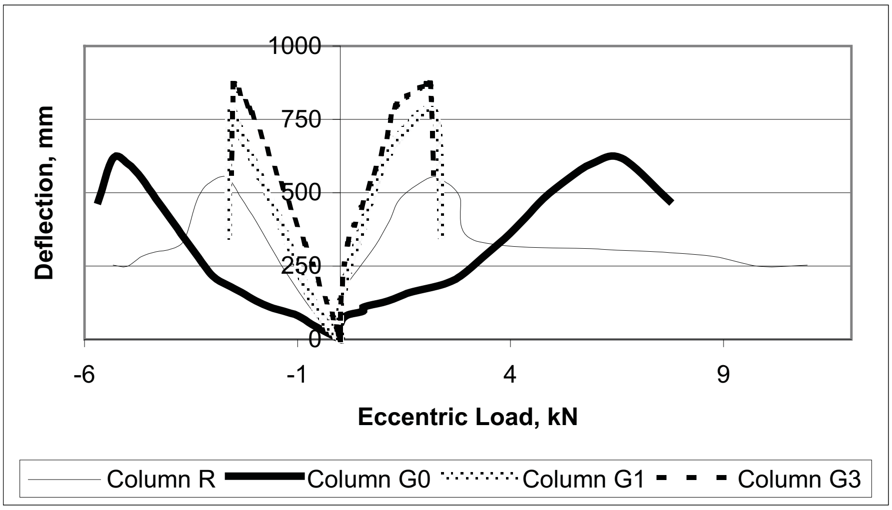

Figure – 7 Load-deflection curves for Columns R, G0, G1 and G3

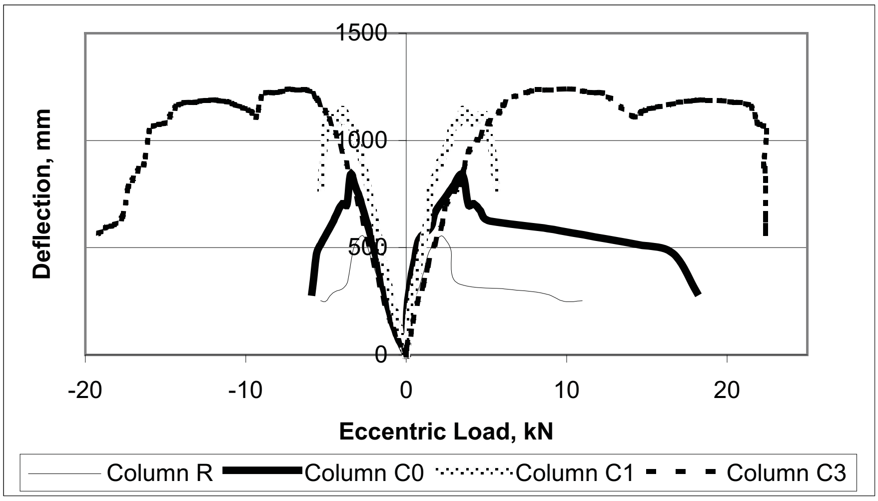

Figure – 8 Load-deflection curves for Columns R, C0, C1 and C3

Table 1 – Configuration of the column specimens.

Column	Dimensions (mm)		Internal Reinforcement	Confining Material	
	Height	Diameter		Horizontal	Vertical
R	925	205	Yes	None	None
G0			None	3 layers GFRP	None
G1			None	3 layers GFRP	1 layer GFRP
G3			None	3 layers GFRP	3 layers GFRP
C0			None	3 layers CFRP	None
C1			None	3 layers CFRP	1 layer CFRP
C3			None	3 layers CFRP	3 layers CFRP

Table 2 – Summary of FRP test results.

Material	**CFRP**		**GFRP**	
Number of layers	1	3	1	3
Thickness (mm)	0.32	1.12	0.5	1.55
Ultimate strength (MPa)	1236.9	971.4	38.2	46.25
Strain at ultimate strength	0.019	0.0245	0.016	0.0195

Table 3 – Summary of column testing results.

Column	Ultimate Load (kN)	Axial deflection at maximum load (mm)	Lateral deflection at maximum load (mm)
R	552	2.65	2.11
G0	617.9	5.32	6.61
G1	766.3	2.59	2.22
G3	871.3	2.51	2.12
C0	856.2	3.61	3.50
C1	1156	4.20	4.77
C3	1240	7.42	10.18

Table 4 – Area under the load-axial deflection curves.

Column	Area under the load-vertical deflection curve kN-mm
R	1648.99
G0	955.55
G1	1533.00
G3	1219.17
C0	2860.64
C1	3879.91
C3	18144.84