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The Behaviour of FRP Wrapped HSC Columns under Different Eccentric Loads

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ABSTRACT: The majority of columns are subjected to a combination of an axial load and a bending moment in one or two directions. With a few exceptions, most of the research in the area of FRP wrapped columns have concentrated on the behaviour of concentrically loaded columns. This paper presents results of testing nine reinforced high strength concrete columns. The column specimens are circular in shape with 205 mm diameter and 925 mm height. Concrete compressive strength was 65 MPa. All columns were reinforced with steel. Three columns were not wrapped, three columns were wrapped with three layers of carbon FRP and three columns were wrapped with three layers of E-glass FRP. From each of the three groups, one column was tested concentrically, one column was tested with a 25 mm eccentric load and one column was tested with a 50 mm eccentric load. Results of testing the columns have shown that the carbon FRP is most effective in increasing the strength and ductility of columns.

Keywords: Reinforced concrete columns, eccentric loading, FRP

1 INTRODUCTION

In recent years, FRP wrapping in lieu of steel jacket has become an increasingly popular method for external reinforcement in which FRP offers improved corrosion and fatigue resistance compared to the steel reinforcement. The high tensile strength and low weight make FRP ideal for use in the construction industry. Another attractive advantage of FRP over steel straps as external reinforcement is its easy handling, thus minimal time and labour are required for installation [1]. With the exception of the work done in references [2-4], most research studies conducted to date on external confinement of concrete columns have mainly concentrated on concentric loading. In practice, very few structural concrete columns are concentrically loaded. Even in a column nominally carrying only axial compression, bending action is almost always present due to unintentional load eccentricities and possible construction error. Also, there are many columns where an eccentric load is deliberately applied. Therefore, studies of concrete columns under eccentric loading are essential for its practical use.

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

2 EXPERIMENTAL PROGRAMME

The experimental programme of this study involved testing nine concrete columns. All the columns were internally reinforced with steel. The steel reinforcement consisted of six N12

(12 mm diameter deformed bars with 500 MPa tensile strength) vertical bars evenly spaced and tied inside with a R10 (10 mm diameter plain bars with 250 MPa tensile strength) helix with a 60 mm pitch. The steel reinforcement was inserted in the column moulds with a 20 mm clearance. Three of the columns had just internal reinforcement, three were wrapped with three layers of carbon FRP, and the last three columns were wrapped with three layers of E-Glass FRP.

Loading of these columns was carried out at three different eccentricities. The first column specimen of each group was tested with an eccentricity of 0 mm, i.e. concentric load, the second column specimen of each group was tested at an eccentricity of 25 mm, and the final column specimen of each group was tested at an eccentricity of 50 mm. Table 1 shows a summary of column specimens.

The concrete compressive strength was 65 MPa. Tests were conducted to determine the tensile strength of the reinforcing steel. These tests revealed that the tensile strength of the reinforcing bars was 525 MPa. The fibres were tested in order to determine their tensile strength. Table 2 shows a summary of the testing.

All columns were tested at the laboratories of the School of Civil, Mining and Environmental Engineering at the University of Wollongong. The testing machine was a 500 tonne Denison compression machine. Especially designed and manufactured loading heads were used for the application of the eccentric loads. Figure 1 shows these heads.

3 EXPERIMENTAL RESULTS

All column specimens were tested to failure. Table 3 shows results of testing the columns. It is clear that the CFRP wrapped columns performed far better than the reinforced columns and the GFRP columns. This higher performance was evident both in the concentrically and eccentrically loaded columns. The GFRP wrapped columns performed better than the reinforced columns.

Column N0 contained internal reinforcement only and was tested under concentric loading. The maximum axial load measured during the experiment as shown in Table 3 was 1925 kN. As shown in Figure 2 the column failed towards the top due to concrete spalling and rupture of the steel reinforcement. The column had a yield axial deflection of 7.02 mm and at failure axially deflected 7.54 mm.

Column C0 contained internal reinforcement, wrapped with three layers of carbon polymer, and tested under concentric loading. The measured maximum axial load was 3970 kN as shown in Table 3. This column failed in the upper section of the column as shown in Figure 3. This failure resulted in the crushing of the concrete, bending of the internal reinforcement and rupture of the carbon fibre external reinforcement. The yield axial deflection was 5.6 mm and the failure axial deflection was 18.56 mm, which is much greater than that recorded for Column N0.

Column G0 was an internally reinforced column wrapped with three layers of E-Glass fibre and tested with concentric loading. The maximum experimental load was found to be 2437 kN as seen in Table 3. As shown in Figure 4 the column failed in its upper section similar to the first two columns. The crushed concrete caused the steel to yield and the polymer to rupture. At yielding the column had axially deflected 6.07 mm, the column continued to deflect and had a final axial deflection of 15.09 mm.

Column N25 had internal reinforcement only and was tested at an eccentricity of 25 mm. For this column the applied load to the column had a maximum value of 1337kN as seen in Table 3. During loading the column started to buckle as shown in Figure 5. After reaching its maximum load the column continued to buckle until the concrete cover broke away and the internal reinforcement split. The column axially deflected 2.62 mm at yielding and then continued to deflect to 4.98 mm at failure. Due to the yielding of the steel reinforcement the column remained bent after failure, while its residual lateral deflection was 35 mm.

Column C25 was an internally reinforced column wrapped with three layers of carbon fibre and tested at 25 mm eccentricity with the experimentally recorded load of the column 1838 kN as seen in Table 3. Failure in the column occurred when the column buckled to the point that the polymer ruptured and the concrete crushed at the centre (see Figure 6). The axial deflection at maximum load was 11.07 mm, however the column continued to buckle until the axial deflection at failure was 17.67 mm. Residual lateral deflection of the column was 35 mm. Even though the column has a same residual deflection as column N25 it laterally deflected more and underwent some elastic recovery.

Column G25 had internal reinforcement and was wrapped with three layers of E-Glass FRP. It was tested at 25 mm eccentricity. The column was found to withstand a maximum load of 1424 kN as seen in Table 3. Failure of the column occurred at the centre similar to Columns

N25 and C25. As shown in Figure 7 the column buckled in the centre causing the concrete to crush, the steel to yield and the polymer to rupture, therefore causing the column to fail. At the maximum load the column had axially deflected 6.87 mm and at failure the column had axially deflected 11.11 mm and laterally deflected 23.11 mm. The residual lateral deflection was 15 mm showing that the column underwent some elastic recovery.

Column N50 had internal reinforcement only and was tested at 50 mm eccentricity. The maximum load on the column was recorded at 552 kN as seen in Table 3. Due to excessive bending in the column the concrete cover spalled off causing failure as shown in Figure 8. The internal reinforcement did not rupture but due to the extent of the spalling the column was considered to have failed. At the maximum load the axial deflection of the column was 2.65 mm.

Column C50 had internal reinforcement and was wrapped with three layers of carbon fibres. The column was tested with an eccentricity of 50 mm. For the experimental work the column withstood a maximum load of 1142 kN as seen in Table 3. The deflection at maximum load was 8.72 mm. After testing the column underwent elastic recovery, which resulted in a residual deflection of 20 mm. As shown in Figure 9, failure occurred once the column buckled to the extent where the concrete snapped in two. A large popping sound was heard when the concrete split. Permanent deformation occurred in the column due the yielding of the steel under the strain. The polymer however stayed intact except for a small amount of separation around the failure area.

Column G50 had internal reinforcement and three layers of E-Glass fibres. Testing was undertaken with an eccentricity of 50 mm. A maximum load of 749 kN was applied to the column before failure as seen in Table 3. At the maximum load the column had axially deflected 4.76 mm, by failure axial deflection had increased to 6.7 mm, while the lateral deflection was 15.4 mm. After testing the column underwent some elastic recovery leaving a residual deflection of 11 mm. Failure occurred at the top of the column. The concrete snapped and the polymer ruptured as shown in Figure 10.

4 RESULTS COMPARISON

The load-deflection curves of the tested columns were recorded and are presented herein.

Figure 11 shows the load-deflection curves of Columns N0, C0 and G0. Figure 12 shows the load-deflection curves of Columns N25, C25 and G25. Figure 13 shows the load-deflection curves of Columns N50, C50 and G50.

In order to explore the effect of the eccentricity on the behaviour of the columns, load deflection curves were plotted for the nine columns. Figure 14 shows the behaviour of the reinforced columns, Figure 15 shows the behaviour of the CFRP wrapped columns and Figure 16 shows the behaviour of the GFRP columns.

Figure 17 shows the effect of the eccentricity on the axial load capacity of the tested column specimens.

Figure 18 shows a photograph of the tested columns specimens. The energy absorbed by each of the columns was calculated as the area under the curve of the axial load versus the axial deflection curve. These energies are shown in Figure 19. It is clear that the CFRP wrapped columns had more energy before collapse.

Based on the experimental work undertaken in this study it can be concluded that the carbon fibre improves the load carrying capacity of the column more than when compared to the E-Glass fibre. This can be seen in the internally reinforced columns where the carbon polymer reinforcement produced loads of 393 kN up to 1533 kN greater than the E-Glass fibre. The wrapped columns both having load carrying capacities greater than the unwrapped columns.

The axial and lateral deflections of the columns were increased by the use of polymer wrapping. With the carbon fibre giving an axial increase of up to 12.69 mm. The E-Glass fibre gave an axial increase of up to 7.55 mm. The exact lateral increase due to the E-Glass fibre is not fully known as the E-Glass fibre wrapped column tested at an eccentricity of 50 mm failed early under minimal loading.

It was found columns wrapped with E-Glass fibre could withstand greater strains than columns wrapped with Carbon fibre. With both types of wrapped columns withstanding greater strains than unconfined columns. As the eccentricity on the column was increased the strains in the column also increased. The internal strain was also noted to be greater than the external strains.

5 CONCLUSIONS

This Study used nine internally reinforced columns with polymer wrapping to test the effect of eccentricity and polymer type The following conclusions are obtained from the experimental work:

– Uni-directional carbon fibre wrapping outperforms plain weave E-Glass when the carbon fibre is wrapped in the longitudinal direction. The carbon allows for greater load carrying capacity on the column and greater axial and lateral deflections without failure.

– As the eccentricity was increased in the columns the load carrying capacity of the columns was significantly reduced. The axial deflection was reduced while the lateral deflection increased with eccentricity.

– The polymer improved the axial and lateral deflection capability of the column when compared to the steel reinfroced concrete column. Steel reinforcement helped to increase the load carrying capacity and the axial deflection of the column while decreasing the lateral deflection.

– Strain in the steel reinforcement was measured at levels greater than the strain generated in the polymer wrapping. Columns wrapped with E-Glass were found to withstand higher levels of strain than columns wrapped with carbon, while the unconfined columns had strain values lower than the columns with polymer wrapping. As eccentricity was increased the strain level in the columns decreased.

– The external confinement with fibre-reinforced polymers can significantly increase the strength of the internal reinforced concrete columns under concentric loading. However, when eccentric loading is introduced, the effectiveness is not significant. The experimental results clearly demonstrated that composite wrapping can enhance the structure performance of concrete column under eccentric loading to some extent, in that composite confinement leads to increased axial load carrying capacity.

– For the circular specimens under concentric or eccentric loading, carbon materials could produce the largest lateral confinement pressure to column specimens.

– The maximum load carrying capacity of a confined column under eccentric load could be directly related to the magnitude of eccentricity, a larger eccentricity results in a smaller maximum load. However, the lateral deflection, which is another important design criterion, has no direct relation with the eccentricities.

– Externally confined concrete column could undergo large deformation without rupture. The extent of deformation could be decided by the strength of FRP composite.

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Table 1. Configuration of column specimens.

Column No.	Confining material	Load Eccentricity (mm)
N0	Helix	0
C0	Helix Carbon-3 layers	0
G0	Helix E-glass-3 layers	0
N25	Helix	25
C25	Helix Carbon-3 layers	25
G25	Helix E-glass-3 layers	25
N50	Helix	50
C50	Helix Carbon-3 layers	50
G50	Helix E-glass-3 layers	50

Table 2. Tensile testing results on FRP specimens.

Specimen	Carbon fibre		E-glass fibre	
Layers	1	3	1	3
Width (mm)	50.5	51.0	49.2	51.3
Length (mm)	175	175	175	175
Thickness (mm)	0.34	1.2	0.5	1.6
Maximum Load (kN)	19.76	62.06	0.94	3.00
Elongation at Maximum Load (mm)	3.48	3.83	2.78	2.80
Maximum Stress (MPa)	1150.8	1014.1	38.2	36.6
Strain at Maximum Stress	0.020	0.022	0.016	0.016

Table 3. Summary of column testing results

Columns	Ultimate load (kN)	Axial deflection at maximum load (mm)	Lateral deflection at maximum load (mm)
N0	1925	7.02	0
C0	3970	18.56	0
G0	2437	6.07	0
N25	1337	2.62	--
C25	1838	11.07	--
G25	1424	6.87	7.30
N50	552	2.65	2.11
C50	1142	8.72	14.1
G50	749	4.76	4.93

Figure 1. Eccentric loading plate and steel plate.

Figure 2 – Column N0 – Internal Reinforcement Only – e=0mm

Figure 3 – Column C0 – Internal Reinforcement with Three Layers Carbon – e=0mm

Figure 4 – Column G0 – Internal Reinforcement with Three Layers E-Glass – e=0mm

Figure 5 – Column N25 – Internal Reinforcement Only – e=25mm

Figure 6 – Column C25 – Internal Reinforcement With Three Layers Carbon – e=25mm

Figure 7 – Column G25 – Internal Reinforcement with Three layers E-Glass – e=25mm

Figure 8 – Column N50 – Internal Reinforcement Only – e=50mm

Figure 9 – Column C50 – Internal Reinforcement with Three Layers Carbon – 50mm

Figure 10 – Column G50 – Internally reinforced with Three Layers E-Glass – e=50mm

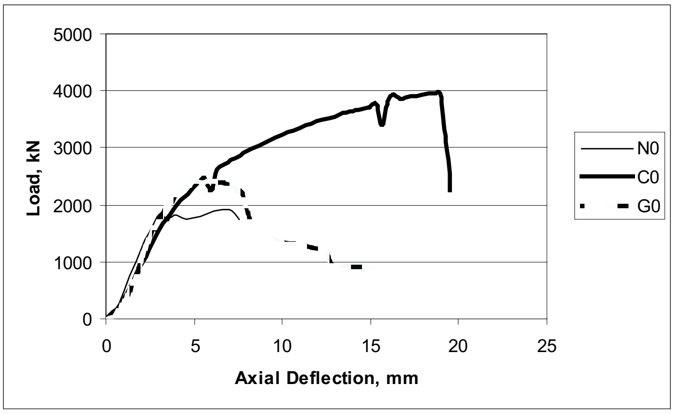

Figure 11. Load-deflection curves of Columns N0, C0 and G0.

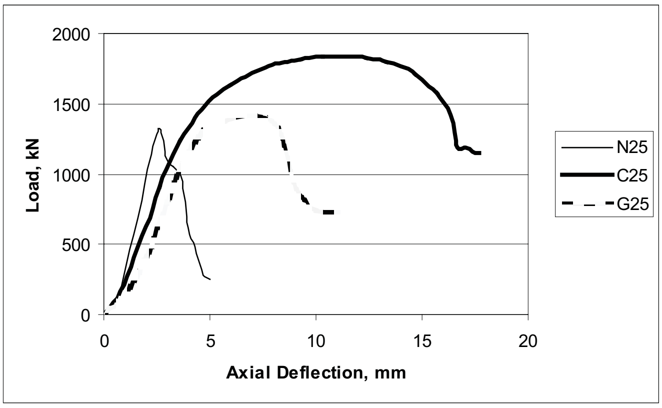

Figure 12. Load-deflection curves of Columns N25, C25 and G25.

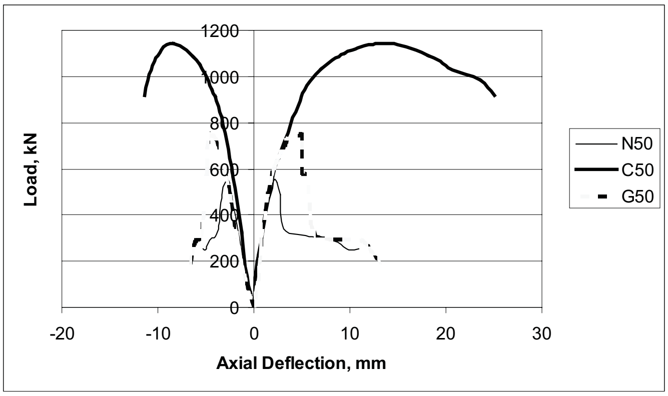

Figure 13. Load-deflection curves of Columns N50, C50 and G50.

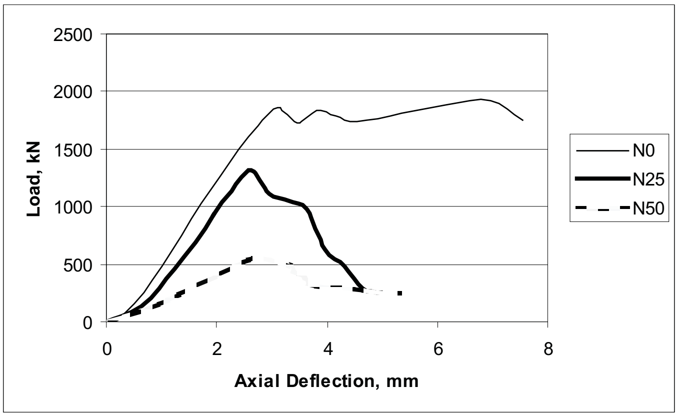

Figure 14. Load-deflection curves of Columns N0, N25 and N50.

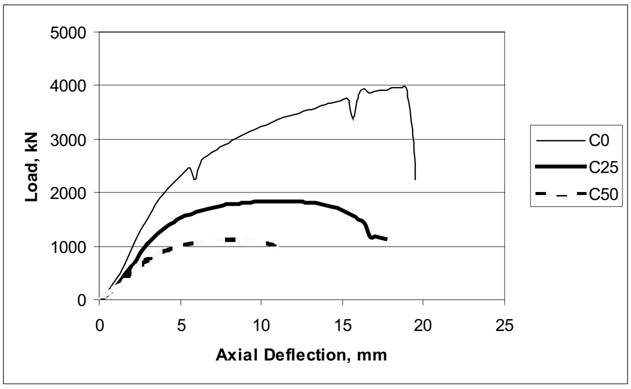

Figure 15. Load-deflection curves of Columns C0, C25 and C50.

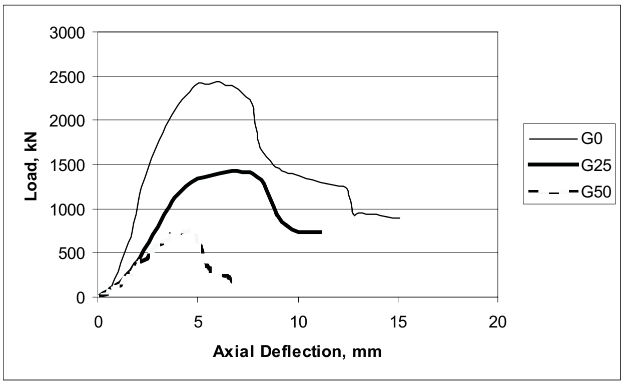

Figure 16. Load-deflection curves of Columns G0, G25 and G50.

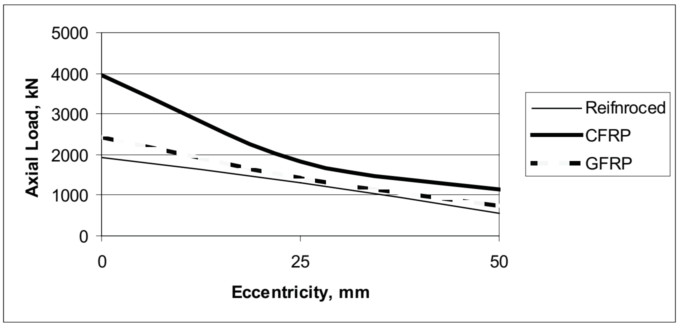

Figure 17. Effect of eccentricity on columns' axial capacity.

N0 C0 G0 N25 C25 G25 N50 C50 G50

Figure 18. Columns specimens after test.

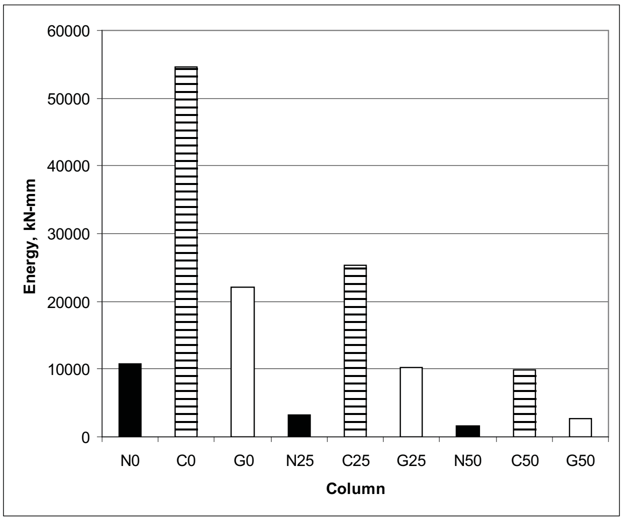

Figure 19. Column absorbed energy before failure.