FRPRCS-14, Belfast - June 2019

Behaviour of BFRP reinforced concrete element under axial loading

Nabi, P.[1], Petkova D.[1], Donchev T.[1], Costas, G.[1], Khorsanditalab, M.R.[1],

[1] Faculty of Science Engineering and Computing, School of Engineering and the Environment
Department of Civil, Engineering, Kingston University, London, UK

Abstract

FRP has to potential to replace steel reinforcement in reinforced concrete (RC) structures primarily due to susceptibility of embedded steel to corrosion. In recent years, the behaviour of concrete members reinforced with fibre-reinforced polymers (FRP) bars have been extensively investigated. However, there is insufficient number of studies related to the behaviour of RC columns under compression. This research experimentally investigates the performance of RC compression members reinforced with Basalt FRP (BFRP) bars. Four large-scale RC specimens with dimensions of 130x130x1500 mm were fabricated and tested under concentric load. The specimens included two steel reinforced columns and two columns internally reinforced with BFRP longitudinal bars. The variable of the experiment are the compressive strength of concrete, C25 and C30. The differences in behaviour of steel and BFRP reinforced columns are discussed and analysed. It was found that BFRP reinforced columns has the potential to be used as replacement to classical steel reinforcement. The BFRP reinforced columns displayed relatively lower ultimate capacity but the failure mode was similar.

Keywords: Reinforced concrete; Column; Internal reinforcement; FRP; BFRP; Compression

Corresponding author's email: k0629429@kingston.ac.uk

1. Introduction

In general, corrosion of steel reinforcement is a major issue in reinforced concrete (RC) structures associated with reduced durability. These problems mostly occur in marine areas and highway bridges, which seem to affect the life expectancy of buildings and bridges in a negative way. Fibre reinforced polymers (FRP) have the potential to become a feasible alternative for replacing steel reinforcement. FRP materials provide several advantages over steel reinforcement such as, lightweight, corrosion resistance, chemical resistance and high tensile strength [1]. Although the initial cost of construction is relatively higher; the total life cycle cost is expected to be less [2]. A number of experimental studies were conducted on the behaviour of FRP as internal reinforcement in RC columns. Increasing the longitudinal reinforcement ratio of GFRP bars increases ductility of the column. Moreover, increasing transverse reinforcement ratio and concrete strength, increase the toughness and ductility [3,5,6,7]. Reducing the spacing between the stirrups can lead to nonlinear increase of specimen strength [4]. The larger amount of longitudinal reinforcement results in increased strength [8]. The existing literature mostly focuses on varying the amount of longitudinal reinforcement, concrete strength, amount and spacing of stirrups. The behaviour of columns constructed with BFRP are significantly less than the columns constructed with CFRP and GFRP bars. The proposed research investigates the behaviour of RC column reinforced with internal BFRP bars.

2. Experimental programme

The study consist of preparing and testing four large-scale samples with dimensions of (130 x130 x 1500 mm) reinforced concrete columns. Two of the columns were reinforced with steel and the remaining two columns were reinforced with BFRP longitudinal bars. Each of the column was constructed with concrete compressive strength of C25 and C30. The samples were reinforced using 10 mm longitudinal bars with 6mm steel stirrups. The links were spaced at 75 mm intervals in the end zones of main reinforcement at each end and 106mm in the mid-span. Anchor bars with diameter of 10 mm and length of 500mm length were welded to steel plates and then placed at the each ends of the columns to avoid premature failure during the testing. The description of samples are describe in table 1

Table 1: Description of samples

S30	S25	B30	B25
Steel reinforced C30	Steel reinforced C25	BFRP reinforced C30	BFRP reinforced C25

2.1 Material properties

Two concrete mixes were prepared: C25/30 and C30/37. The samples were prepared at Kingston University Laboratory. Natural aggregates with a maximum diameter of 10 mm were used in the concrete mix. The samples were left for the 28 days in the curing room prior to testing. The compressive strength of the concrete was obtained during the day of testing. The BFRP bars used in the experiment were sand coated with tensile strength of 1000 MPa and elastic modulus of 45GPa. High yield steel reinforcement with a minimum yield strength of 500 MPa were used in the experiment.

2.2 Instrumentation and testing setup

Steel plates were attached to the top and bottom of the column in order provide a levelled loading surface and prevent load eccentricity. The sample was instrumented Linear Variable Differential Transducers (LVDTs) at the supports in order to monitor the vertical displacement. Two dial gauges were placed at the mid-span of the column to measure the lateral deflection of the columns. Strain gauges were attached at the centre-point of the internal reinforcement and at the surface of the concrete in order to monitor its behaviour. The load was applied axially at a rate of 0.05 kN/min and the columns were tested under destruction. Dension compression machine was used to the testing purposes as shown in Fig 1. The samples were monitored regularly and the performance of the samples were recorded throughout the experimental procedure.

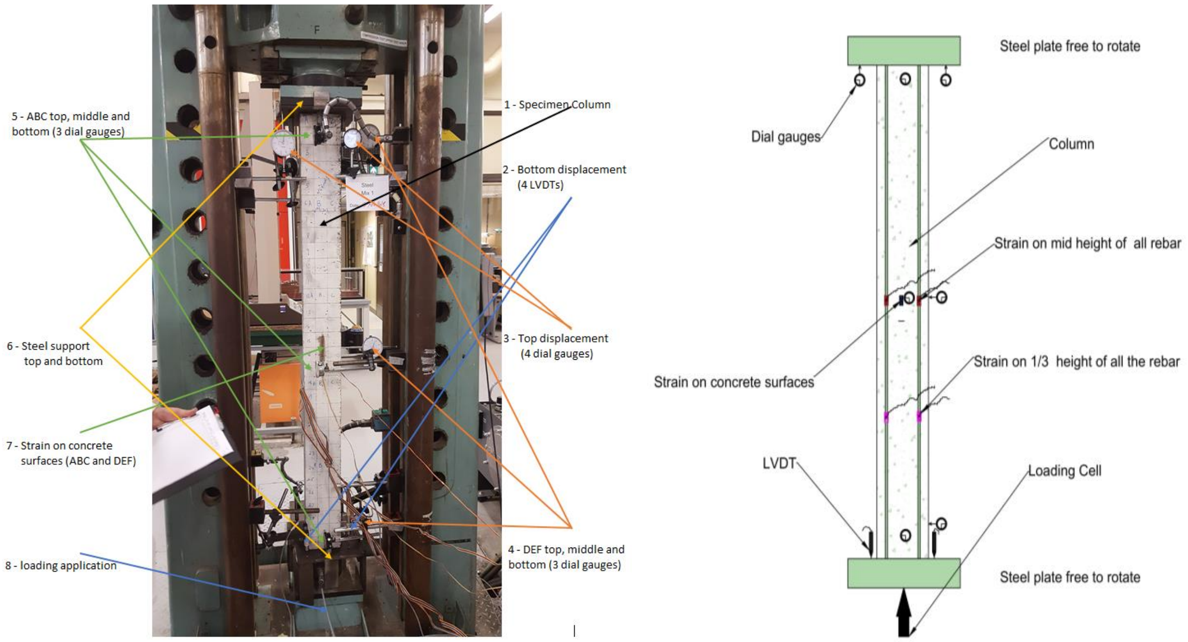

Figure 1: (a) Test setup (b) Instrumentation

3. Test results and Discussion

The graph showing the load-axial deformation for the tested sample is shown in Fig 2. The negative curvature at the initial stages of loading shows settlement of the column inside the testing rig. The axial deformation for all the sample were relatively similar. The slope of the graph for the steel and BFRP reinforced column throughout the loading is roughly similar. With the increasing amount of load, the columns started to bend to one direction. It was followed by cracking and spalling of the concrete at the mid-section of the column. After reaching to maximum load, the steel bars started to yield while the BFRP bars ruptured. The failure mode was rather gradual and occurred over a considerable amount of time. The columns maintained to carry a significant amount of load after reaching to its peak load. It should be noted that the sample made with concrete strength of C30 displayed lower level of energy dissipation as compared to columns made with concrete strength of C25. Reduction in strength of concrete results in a more gradual mode of failure.

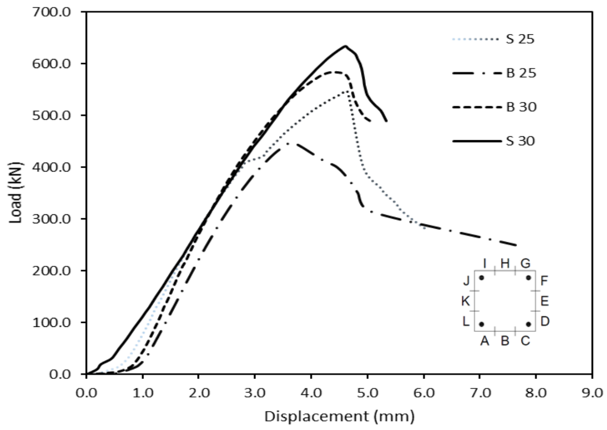

Figure 2: Load vs axial deformation

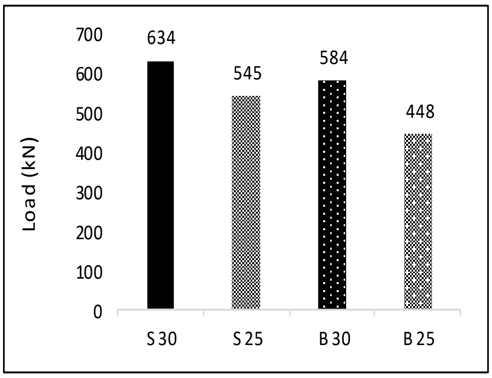

Figure 3: Ultimate load

The ultimate load for all the sample is presented in Fig 3. In general, the steel reinforced samples displayed higher ultimate load compared to its BFRP reinforced counterparts. The ultimate load difference for the columns made with concrete of C30 is around 8% whilst for the columns made with concrete of C25 is 18%. The results suggests that the performance of BFRP reinforced concrete are somewhat comparable.

4. Conclusion

BFRP reinforced columns could be used as an alternative to steel reinforced columns. Although the ultimate load of BFRP samples are lower; the variation in peak load is not so significant. BFRP reinforced columns can achieve up to 82% of the ultimate capacity of steel reinforced columns for C25 and up to 92% for C30. Most importantly, the load-deflection behaviour of the steel and reinforced samples were very similar.

References

[1] Page, C.L., 1975, “Mechanism of corrosion protection in reinforced concrete marine structures Nature,” 258 pp. 514-515.

[2] Pantelides, C., Gibbons, M., Reaveley, L., 2013, “Axial load behaviour of concrete columns confined with GFRP spirals,” J. Compos. Constr. 17 (3), pp. 305-313.

[3] Lotfy, M.L., 2011, “Behaviour of reinforced concrete short columns with fiber reinforced polymers bars,” International journal of Advanced Structural Engineering, 3 (1), pp. 43-55.

[4] Tobbi, H., Farghaly, A. S., and Benmokrane, B., 2012, "Concrete Columns Reinforced Longitudinally and Transversally with Glass Fiber-Reinforced Polymer Bars," ACI Structural Journal, 109 (4), pp. 551-558.

[5] Tobbi, H., Farghaly, A.S., Benmokrane, B., 2014, “Behavior of concentrically loaded fiber-reinforced polymer reinforced concrete columns with varying reinforcement types and ratios,” ACI Structural Journal, 111 (2), pp. 375-385.

[6] Karim, H., Sheikh, M.N., Hadi, M.N.S., 2016, “Axial load-axial deformation behaviour of circular concrete columns reinforced with GFRP bars and helices,” Constr. Build. Mater. 112, pp. 1147–1157. https://doi.org/10.1016/j.conbuildmat.2016.02.219

[7] Hadhood, A., Mohamed, H.M., and Bemokrane, B., 2017, “Failure Envelope of Circular Concrete Columns Reinforced with Glass Fiber-Reinforced Polymer Bars, and Spirals. ACI Structural Journal. 114 (6), PP. 1417-1428.

[8] De Luca, A., Matta, F., Nanni, A., 2009, “Behaviour of Full-Scale Concrete Columns Internally Reinforced with Glass FRP Bars under Pure Axial Load,” Composites & Polycon. American Composites Manufacturers Association. Januaray 15-17, Tampa FL, USA.