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The Behavior of Retrofitted GPC Columns under Eccentric Loading †

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Abstract: Geopolymer concrete (GPC) has been the subject of ongoing research as a suitable substitute for conventional concrete production because of its benefits for the environment. However, there is little research regarding retrofitting the structural part if a GPC member fails. The current study thus concentrates on the damaged GPC structural members/columns. For this purpose, twelve columns which include four CC columns, four GPC Columns, and four FRGPC columns, were retrofitted with CFRP sheets and tested in the electrohydraulic testing apparatus (5000 kN). The results showed significant improvement in the ultimate load value of all 12 columns. Axial strain in all 12 columns also increased significantly. The ductility index of the columns was also calculated using axial strain values. The axial load–displacement behavior, ductility, and loading capacity of the evaluated columns are all significantly improved by the addition of steel fibers.

Keywords: carbon fiber reinforced polymer (CFRP); eccentricity; fiber reinforced geopolymer concrete (FRGPC); geopolymer concrete (GPC)

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1. Introduction

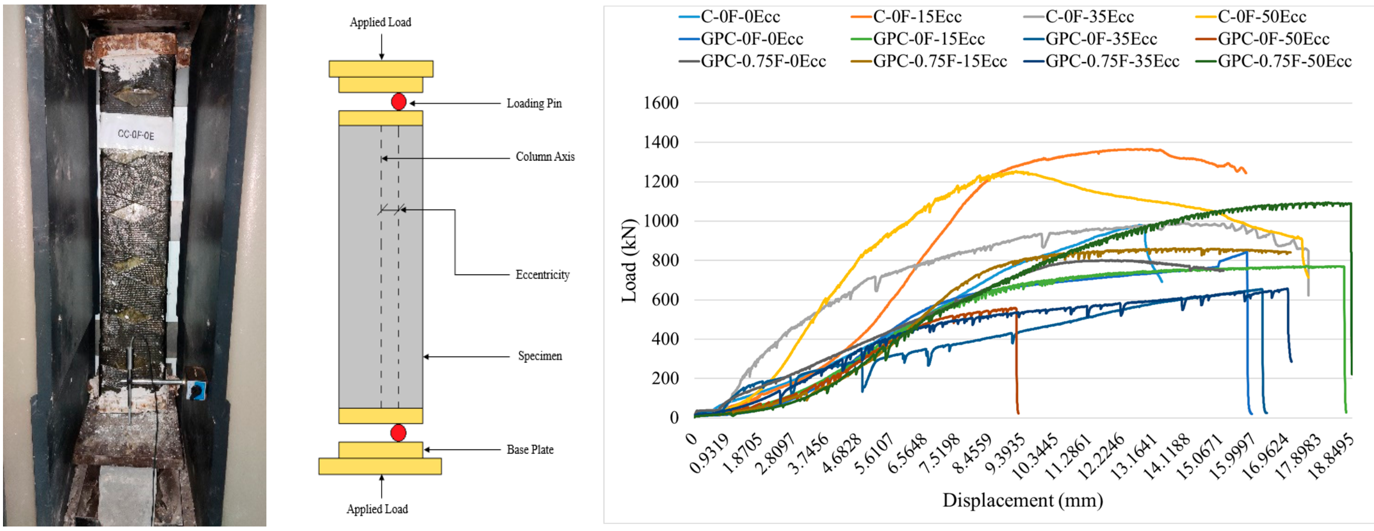
Geopolymer concrete (GPC) has evolved as a new option that may completely eliminate the need for cement while promoting the efficient use of waste materials. However, if a GPC structural member fails, there is little study about the retrofitting of that member. Therefore, the present study focuses on the damaged GPC structural columns. Fiber-reinforced polymer (FRP) composites, the newest modern composite materials, have recently surpassed conventional retrofitting techniques in demand. FRP jackets are the ideal material because of their high rigidity and high strength-to-weight ratio. As a result, FRP has seen significant application in retrofitting.

Numerous tests and theoretical analyses have clearly proved that wrapping FRP composites around columns is a very successful approach. Yang et al. investigated the eccentric compression loading of rectangular high-strength concrete columns restricted with carbon fiber-reinforced polymer (CFRP) [1]. Zeng et al. investigated the cyclic axial compression behavior of FRP spiral strip-confined concrete [2]. Askandar et al. examined the behavior of RC beams reinforced with FRP strips under the combined action of torsion and bending [3]. For FRP spiral strip-confined concrete, Liao et al. researched the stress–strain behavior and design-oriented model [4]. The partially FRP strengthening approach is a viable option, particularly for columns that require moderate increases in strength and deformation capacity [5].

In light of the previously mentioned, the purpose of this research is to explore the axial compressive behavior of partially FRP confined Fiber Reinforced Geopolymer Concrete (FRGC). The current investigation involved the retrofitting and testing of 12 columns using CFRP.

2. Experimental Procedure

A total of 12 columns with cross-sections of 200 mm square and heights of 1000 mm were examined in the present study. Six deformed 12 mm diameter bars were used to brace the columns longitudinally. In all instances, transverse reinforcement was supplied as closed ties of diameter 6 mm bars spaced 100 mm from centers. Deformed steel with a yield strength of 300 MPa for D6 (6 mm) bars and 450 MPa for D12 (12 mm) bars was employed. CFRP wrapping of the columns was carried out using a unique pattern, as shown in Figure 1a. The results are compared between CC columns and GPC columns. In order to evaluate the columns, two loading scenarios were used, concentric loading and eccentric loading with varying eccentricities (eccentricity e = 15, 35, and 50 mm). Sample details are given in Table 1.



(**a**) (**b**)

Figure 1. (**a**) Load mechanism for CFRP columns; (**b**) ultimate load of CC and GPC columns.

Table 1. Mix proportion and material quantities of mixes [6].

Sr. No.	Group ID	Specimen ID	Mix Proportion			Mix Quantities (kg/m^3)								
			OPC	FA	SG	Sand	CA	OPC	FA	SG	NaOH	Na_2SiO_3	SP	Water
1	CC	C-0F-0Ecc	100%	-	-	640	1201	370	-	-	53	107	4	170
		C-0F-15Ecc	100%	-	-	643	1206	370	-	-	53	107	4	170
		C-0F-35Ecc	100%	-	-	640	1201	370	-	-	53	107	4	170
		C-0F-50Ecc	100%	-	-	643	1206	370	-	-	53	107	4	170
2	GPC	GPC-0F-0Ecc	-	50%	50%	643	1206	-	200	200	53	107	8	-
		GPC-0F-15Ecc	-	50%	50%	643	1206	-	200	200	53	107	8	-
		GPC-0F-35Ecc	-	50%	50%	646	1212	-	200	200	53	107	8	-
		GPC-0F-50Ecc	-	50%	50%	643	1206	-	200	200	53	107	8	-
		GPC-0.75F-0Ecc	-	50%	50%	643	1206	-	200	200	53	107	12	-
		GPC-0.75F-15Ecc	-	50%	50%	644	1208	-	200	200	53	107	12	-
		GPC-0.75F-35Ecc	-	50%	50%	643	1206	-	200	200	53	107	12	-
		GPC-0.75F-50Ecc	-	50%	50%	647	1214	-	200	200	53	107	12	-

2.1. Preparation of Specimen

Firstly, the repairing of the specimens is carried out using geopolymer mortar having 50% fly ash and 50% slag as a binder. The specimens were then dried in atmospheric conditions for 28 days. Secondly, retrofitting of the specimens was carried out using CFRP sheets 3 mm thick having a width of 82 mm. A total of four CFRP sheets were used for wrapping each specimen, two clockwise and two anti-clockwise, at an angle of 20°. The CFRP should be placed firmly against the GPC and CC surface in order to make good contact and remove any air pockets between it and the concrete surface.

2.2. Testing

At 28 days, unidirectional axial loading was given to each specimen. A 5000 kN capacity electrohydraulic testing equipment was used to apply the loading. Under displacement control conditions, the columns were tested to the point of failure. The load was applied at regular 1 mm/s intervals. For the concentrically loaded columns, a similar system was employed, but there was no loading pin. In order to prevent columns from failing prematurely due to overstressing, steel collars of thickness 3.2 mm having a width of 76 mm were attached at both ends of each column prior to testing. On the top and bottom sides of the columns, a thin coating of Plaster of Paris was also used to provide a level surface for the test's uniform weight distribution. A magnetic Linear Variable Differential Transformer (LVDT) of 20 mm capacity and 0.001 mm accuracy was vertically aligned with the base plate of the machine to measure the axial deformation in the specimen.

3. Research Methodology

First, the surface of the specimen was prepared, and any loose or broken material was removed. Second, a geopolymer mortar with a binder made of 50% fly ash and 50% slag is used to repair the specimens. Wrapping of CFRP strips was carried out around the column after applying the bonding agent to the finished surface of the column, make sure the CFRP strips were at a 20-degree angle with the column's horizontal axis. Use a 20 mm capacity magnetic LVDT and electrohydraulic testing apparatus (5000 kN), which can show the structural performance and behavior of the columns. The LVDT is accurately positioned and calibrated in order to precisely measure the vertical deflection of the column during the test. As we gradually added force to the column until it reached its full capacity, we set the deflection rate to 1 mm per minute. We then took the deflection data that the LVDT computer supplied to chart the behavior of the column as the load increased. We repeated the test until the column failed or started to distort visibly.

4. Results

The ultimate load of the specimens obtained from the experimental results is shown in Table 2. We can clearly see that the specimens from the GPC group showed lower ultimate load values than those from the CC group. The ultimate load of CC, GPC, and FRGPC columns was improved from previous results. The ultimate load values after retrofitting shows significant improvement. The fact that the ultimate load of the FRGPC column on concentric loading is lower than the previous value is due to the rusting of steel fibers present in the specimen. Figure 1b demonstrates how changing the value of eccentricity in the tested specimens affects load levels. In other words, as the eccentricity of the axial load increases, the ability of the column to carry loads decreases, which is linked to its eccentricity. The ductility index for all specimens was also calculated.

Table 2. Columns axial strength and ductility index.

Sr. No.	Group ID	Specimen ID	Quantity of Fiber (%)	Eccentricity	Before Retrofitting P_{max} (kN)	After Retrofitting P'_{max} (kN)	Axial Deformation at P'_{max} (mm)	Ductility Index
1	CC	C-0F-0Ecc	0	0	945	980.498	12.741	1.01
		C-0F-15Ecc	0	15	712	1366.153	13.043	1.21
		C-0F-35Ecc	0	35	430	994.696	13.485	1.35
		C-0F-50Ecc	0	50	330	1253.35	9.197	1.89
2	GPC	GPC-0F-0Ecc	0	0	860	844.977	14.959	1.00
		GPC-0F-15Ecc	0	15	570	771.793	17.505	1.07
		GPC-0F-35Ecc	0	35	335	654.541	16.241	1.01
		GPC-0F-50Ecc	0	50	249	559.063	9.133	1.01
		GPC-0.75F-0Ecc	75%	0	1000	801.639	11.621	1.30
		GPC-0.75F-15Ecc	75%	15	720	861.009	13.741	1.24
		GPC-0.75F-35Ecc	75%	35	460	657.994	17.052	1.01
		GPC-0.75F-50Ecc	75%	50	340	1095.335	18.170	1.04

5. Conclusions

The main focus of this research is to provide the proper solution for retrofitting GPC columns. From all the above research, we can now say that CFRP wrapping of GPC columns is a violable solution. This paper presents the results of twelve columns, including four reference columns, four GPC columns, and four FRGC columns. All 12 columns were wrapped with CFRP sheets in a particular manner. The ultimate strength of the CC columns, GPC columns, and FRGPC columns was compared to a previous study due to retrofitting. Considering the experimental and theoretical findings in this research, the ultimate load values of CC columns, GPC columns, and FRGPC columns increased from the values that were obtained from previous studies. The axial displacement of all the columns also significantly improved. The ductility index of all 12 columns also increased.

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