ENHANCING LOAD-CARRYING CAPACITY OF DAMAGED GEOPOLYMER CONCRETE COLUMNS BY RETROFITTING WITH CFRP WRAPS

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Abstract- An environmentally friendly substitute for conventional concrete is geopolymer concrete, which are created from by-products of industry such as fly ash, slag, quarry rock dust (QRD) and other aluminosilicate minerals. This test study includes eight specimens of 200mm x 200mm x 1000mm which were already tested to the Ultimate load carrying capacity. The specimens include four GCD columns with 0% fiber and four GCD columns with 0.75% fiber. The damaged specimens were first repaired by GCD (Geopolymer concrete with QRD), and then retrofit with CFRP sheets by wrapping around the column using epoxy adhesives and tested under the compression testing machine (5000 KN) at concentric and eccentric loading (at 15E, 35E, 50E) with a 20 mm magnetic LVDT. As a result, the column's load-bearing capacity, flexural strength, ductility, is improved by retrofitting columns with CFRP sheets, which is a minimally invasive, high strength-to-weight ratio, and low thermal expansion.

Keywords- Geopolymer concrete, Strengthening, Retrofitting, Carbon fiber reinforced polymer (CFRP)

1 Introduction

Geopolymer concrete encourages resource efficiency, protects natural resources, and helps to reduce carbon emissions[1]. A further benefit of geopolymer concrete is its exceptional resilience, which lowers the frequency of repairs and replacements while increasing the life of buildings[2]. A geopolymer binder is combined with aggregates like sand, gravel, and crushed stone to create geopolymer concrete, as opposed to conventional concrete, which is manufactured using Portland cement[3]. An alumina and silica source, such as fly ash, crushed granulated blast furnace slag, or quarry rock dust is combined with an alkali activator solution, such as sodium silicate solution (12M) to create the geopolymer binder. With the passage of time, environmental factors like, temperature changes, chemical reactions, and moisture comes in contact with all the constructions including reinforced concrete columns which can cause deterioration of concrete and corrosion of reinforcing steel[4]. Mechanical stress poses a threat, to the columns potentially causing cracks, deformities and structural failure when subjected to vibrations and impacts[5].

One effective method to enhance the strength and durability of columns is through the use of Carbon Fiber Reinforced Polymer (CFRP) strengthening [6]. CFRP is resistant to corrosion reinforces structures significantly without adding weight and can be easily attached to column surfaces. Its flexibility allows it to absorb energy during earthquakes reducing the risk of failure [7]. Moreover CFRP sheets offer lasting toughness and protection to the elements. This strengthening technique enhances load bearing capacity, stiffness and resilience, under different loading conditions including sesmic stresses.

2 Research Methodology

The columns were 200 mm x 200 mm in cross-sectional dimension and had a height of 1000 mm. Eight of the columns were examined, repaired, and their tensile strengths have been compared with those of formerly examined columns without CFRP. The columns were reinforced with six 12 mm Dia bars having yield strength of 450 MPa as the main reinforcement and 6 millimeters Dia @100mm center to center having yield strength of 300 MPa as the transverse reinforcement. For repair, firstly remove the loose or broken material from the columns. Apply the repair material, whose composition is specified in section 2 of [8], after removing. After repairs, give the seven-day curing time- to columns, and smoothen the column's surface using a grinder once it has gained enough strength.

After smoothening the surface, apply the binding material to the columns and wrap the CFRP strips (20 mm) at a 20-degree angle. Apply pressure while applying to ensure that the CFRP strips are free of air bubbles and wrinkles. Use a compression testing machine (5000 KN) with a 20 mm magnetic LVDT (Linear Variable Differential Transformer) to test the columns to see how they perform structurally. The LVDT is properly placed to measure the deflection exactly. Apply force to columns until they reach their yielding point with the deflection rate set to 1 mm per minute. Take the deflection values that the LVDT computer has produced to check the column behavior.

2.1 Preparation of specimens

To prepare the samples, the GCD surface was cleaned and made ready. Loose or damaged material, dust, filth, or other pollutants were removed by hammering them out of the specimens. After removing any loose debris, surface cracks were filled with GCD mortar (50% FA + 30% Slag + 20% QRD) using NaOH and Na2SiO3 as alkali activators. The same GCD mix design used which was already used in the preparation of the specimen, taken from table 1 of [8]. The exterior of the column was ground rough to strengthen the bond between its surface as well as the CFRP. After grinding, the holes were filled with epoxy to create an equal surface and prevent air pockets. Chemdur-300 (components A and B) were combined and applied in a 2:1 ratio to the GCD surface as a bonding agent to create a strong connection between the concrete and the CFRP (Figure 1c). The CFRP was cut into an appropriate strip size of 82 mm wide, and 10 ft (3048 mm) long based, and wrapped it on columns at 20^0 angle (Figure 1b). The GCD columns surface was coated with CFRP using the bonding agent Chemdur 31(Figure 1a), and to get rid of any air pockets between the concrete surface and CFRP, then the CFRP should be pressed firmly against the surface to create solid contact.

Figure 1: Preparation of specimen, a. CHEMDUR 300 (component A and B), b. Covered column by CFRP strips at 20^0, and c. Applying bonding agent on column.

2.2 Testing

The test subjects were subjected to axial unidirectional force until total failure, and a schematic sketch of concentric loading is shown in (Figure 2a). The load was delivered in periodic intervals of 1 KN/s. Before testing, a pair of 76mm wide by a thickness of 3.2 mm thick steel collars were wrapped around both ends of a column to avoid overstressed premature failure

A layer of plaster of Paris with a sufficient thickness was applied to each of the upper and lower faces of the column to ensure a uniform transfer of load (Figure 2b). The axial displacement of columns under 5000KN CTM and at a deflection rate of 1mm/minute was measured using a 20 mm magnetic LVDT device (Figure 2c).

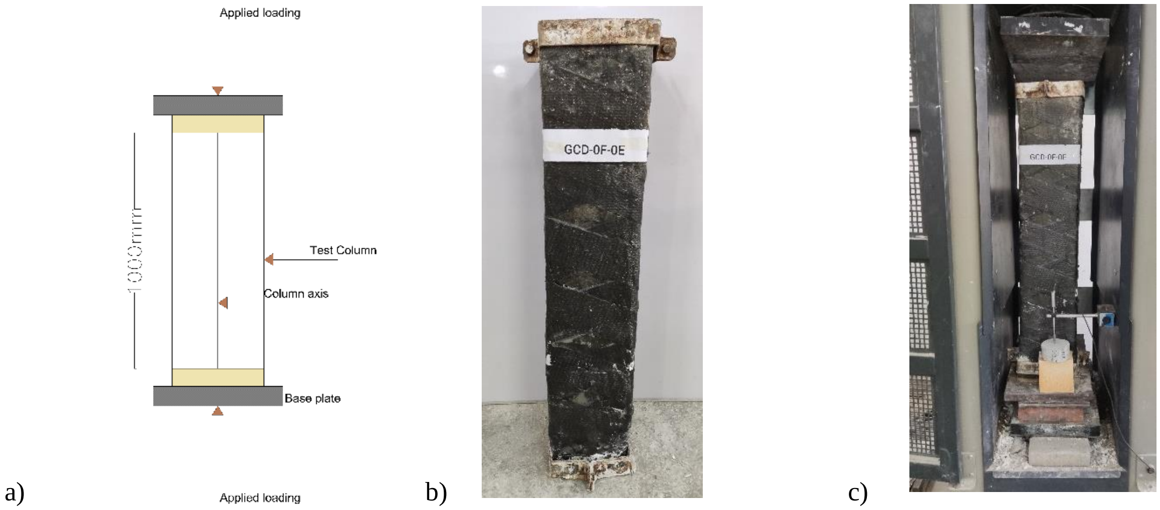

Figure 2: Testing of specimen, a. Schematic sketch of concentric loading, b. Specimen before testing, and c. Specimen placed in CTM with magnetic LVDT

3 Results

Table 1 shows that the GCD columns without fiber follows the trend, as the eccentricity (E) increases load bearing capacity of the columns is decreased from 0E to 50E. But the ultimate load of these columns was improved from previous results. On the other hand, GCD columns with fiber did not follow any trend. Firstly, at 0E ultimate load goes down by 19.9%, at 15E it increases but at 35E it again decreases and shows its maximum at 50E. The reason for showing lower value at concentric loading is due to the rusting of fibers and reinforcement in the column which affects the ultimate load of the columns. After strengthening columns results are compared with, without CFRP columns results [8]. The graph is drawn between the Ultimate load carrying capacity (Pmax) in KN and Displacement (mm) from the data obtained from the LVDT computer (Figure 3a).

Table 1 post-strengthening performance of structural elements

Gr. no.	Gr. ID	Col. ID	Fiber Fr.	E (mm)	Pmax (KN)	Percentage Improvement %	Axial displacement at Pmax (mm)	Ductility Index (DI)
1	GCD	GCD-0F-0E	--	0	1105	39.8	13.5	1.13
2		GCD-0F-15E	--	15	697	35.3	14.6	1.08
3		GCD-0F-35E	--	35	570	95.2	10.3	1.06
4		GCD-0F-50E	--	50	451	124.3	7.8	1.01
5	GCD	GCD-0.75F-0E	0.75%	0	759	-19.9	13.9	1.15
6		GCD-0.75F-15E	0.75%	15	782	19.6	11.1	1.07
7		GCD-0.75F-35E	0.75%	35	654	68.6	16.3	1.02
8		GCD-0.75F-50E	0.75%	50	861	224.9	18.4	1.04

a)

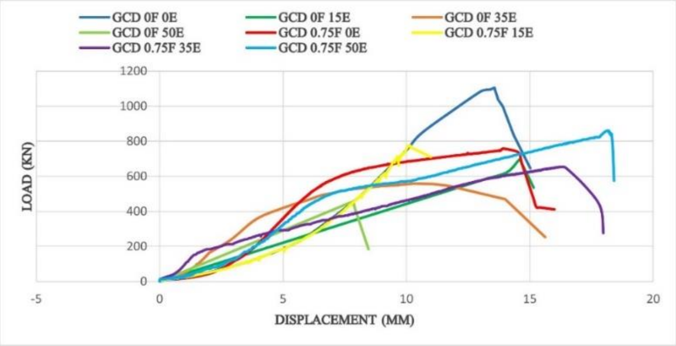

Figure 3: Columns Ultimate load Graph, a. Strengthened Geopolymer concrete column graph between load and displacement.

4 Practical Implementation

CFRP sheets or strips can be externally bonded to the tension face of beams and columns to increase their load-carrying capacity and flexural strength. For concrete slabs with inadequate shear strength, CFRP can be applied to the slab's underside to enhance its shear resistance. Furthermore, where steel structures have suffered from corrosion, CFRP can be employed as a seismic and durable external reinforcement.

5 Conclusion

Eight columns, whose dimensions were 200 x 200 x 1000 mm were used in this research. For strengthening, CFRP technique is used to increase the structure durability and strength. From the results it is demonstrated that the strength of geopolymer concrete column without fiber follows a trend and showed its maximum at 0E (1105 KN) followed by 15E (697 KN), 35E (570 KN), and (451 KN) at 50E by wrapping 20mm CFRP strips at 20°. Other the other hand, GCD columns with fiber showed a different behavior due to the rusting of fibers and showed a maximum at 50E (861 KN), followed by 15E (782 KN), 0E (759 KN), and (654 KN) at 35E. It is concluded from the above discussion that, as the eccentricity of GCD columns increases the ultimate load bearing capacity of the columns is decreased. Secondly, strength of destructed columns is increased by CFRP sheet by wrapping at 20^0 angles from the horizontal and by this method the need to destroy and rebuild the structural elements is eliminated.

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Reference

[1] M. A. Ansari, M. Shariq, and F. Mahdi, "Geopolymer concrete for clean and sustainable construction–A state-of-the-art review on the mix design approaches," in *Structures*, 2023, vol. 55: Elsevier, pp. 1045-1070.

[2] T. Stengel, J. Reger, and D. Heinz, "Life cycle assessment of geopolymer concrete–what is the environmental benefit," *Concrete Solutions*, vol. 9, 2009.

[3] B. Al Muhit, K. Foong, U. Alengaram, and M. Z. JUMAAT, "Geopolymer concrete: A building material for the future," *Electronic Journal of Structural Engineering*, vol. 13, no. 2, pp. 11-15, 2013.

[4] C.-K. Ma, A. Z. Awang, and W. Omar, "Structural and material performance of geopolymer concrete: A review," *Construction and Building Materials*, vol. 186, pp. 90-102, 2018.

[5] A. Hassan, M. Arif, and M. Shariq, "Use of geopolymer concrete for a cleaner and sustainable environment–A review of mechanical properties and microstructure," *Journal of cleaner production*, vol. 223, pp. 704-728, 2019.

[6] G. T. Truong, J.-C. Kim, and K.-K. Choi, "Seismic performance of reinforced concrete columns retrofitted by various methods," *Engineering Structures*, vol. 134, pp. 217-235, 2017.

[7] R. D. Iacobucci, S. A. Sheikh, and O. Bayrak, "Retrofit of square concrete columns with carbon fiber-reinforced polymer for seismic resistance," *Structural Journal*, vol. 100, no. 6, pp. 785-794, 2003.

[8] R. M. Waqas and F. Butt, "Behavior of Quarry Rock Dust, Fly Ash and Slag Based Geopolymer Concrete Columns Reinforced with Steel Fibers under Eccentric Loading," *Applied Sciences*, vol. 11, no. 15, p. 6740, 2021.