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Compression Behaviourur of Damaged Reinforced Concrete Columns Confined with Ferro Geopolymer Jacket

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This research concentrated on the structural behavior of retrofitting RC columns by ferrogeopolymer confinement subjected to axial loading. Fly ash (FA) and ground granulated blast furnace slag (GGBS) based geopolymer (GP) mortar, activated with sodium hydroxide (NaOH) and sodium silicate (Na2SiO3), cured at a temperature of 30 ºC was used. six columns of M25 grade reinforced concrete (RC) columns were subjected to 80% of the ultimate load. Then all the columns were jacketed by using ferro geopolymer mortar with 25 mm thickness, reinforced with 1, 2 and 3 layers of expanded metal mesh (EMM) and welded wire mesh (WWM) cast around damaged concrete columns. The performance of ferro geopolymer confinement RC columns was examined with consideration to the mid-span deflection, first crack load, ultimate failure load and ductility index. Both expanded metal mesh and welded wire mesh of ferro geopolymer jacketed columns showed greater ultimate failure load and higher ductility index than the RC column. The results from the experiment were compared with the theoretical results obtained from the modified ECP 203 and modified ACI 318 equation codes.

Keywords: Ferro geopolymer jacket, Compressive strength, Fly ash and GGBS, Expanded metal mesh and Welded wire mesh, Ductility index.

1. Introduction

Reinforced concrete (RC) columns bear the weight of both slabs and beams and frequently categorized as the most important part of the building superstructure. The RC building's collapse may arise as a result of change in the service load and inadequate column strength that via degradation. Over the previous several decades, the prevalence of failure in the widespread use of reinforced concrete (RC) structures is due to growing service loads and/or issues with durability. Economic damages as a result of Millions of dollars are lost on such failures. Many structures in civil society are not any no longer regarded as secure due to overloading, below the standard of current frameworks or an absence of internal oversight. In order to ensure effective serviceability, Older or damaged structures need to be renovated.

Rehabilitation of concrete members is very important to extend their service period in the face of overloading and chemical attacks in aggressive environments. Repair and strengthening of damaged concrete structurs is usually done by constructing external jackets to enhance additional strength, stiffness and ductility [12-15].

Retrofitting should be done in two ways, one is global retrofitting and second is local retrofitting. In global retrofitting the whole structure is retrofitted to satisfy the serviceability requirements, but in case of local retrofitting only a predetermined part of the structure is reinforced. Global retrofitting can be done in RC structures by adding shear walls, adding infill walls, adding bracings and so forth. Local retrofitting is a technical method in which an essential part of structure is retrofitted and this can be carried out by jacketing of beams, jacketing of slabs, jacketing of columns, jacketing of beam column join and so on. Jacketing construction is one of the most favored technique in retrofitting of RC structures. Ferrocement and FRP jacketing are the viable techniques in retrofitting of RC columns. In this research ferrogeopolymer confinement was used for retrofitting of damaged RC column.

One of the less expensive and easier-to-use alternatives for strengthening and repairing damaged RC columns is ferro geopolymer jacketing. The most common mesh types utilized in ferro geopolymer applications are expanded metal wire mesh, woven wire mesh, hexagonal wire mesh, and welded wire mesh. In general, it can be said that the kind and orientation of the ferro reinforcement utilized have a significant impact on the ferro geopolymer's characteristics.

2. LITERATURE REVIEW

Kothya Heng [13] et al (2017) : In his paper, investigate the behavior of concrete cylinders confined with a ferro-geopolymer jacket in axial compression. Each cylinder is confined with one, two and three layers of EMM ferrogeopolymer jacket having a 25mm thickness. Concluded that ferro geopolymer confinement in enhancing the compressive strength and axial stiffness of cylinder specimens.

Bulu Pradhan [12] et al (2009) : Investigated use of ferrocement confinement to concrete cylinder specimens with a size of 150mm X 300mm. The experimental results showed that ultimate compressive strength of concrete can be enhanced by confined concrete specimens.

Sugama et al (2005) : Studied and conduct the acid resistance test on fly ash GGBS based geopolymers. Different combinations between GGBS and fly ash was fixed as 90:10, 80:20, 70:30, 60:40 and 50:50 by weight. The geopolymers made with the 50% GGBS and 50% fly ash combination were suffered minimum weight loss and less strength deterioration. Also the compressive strength of the geopolymer were substantially improved by using this mix combination.

Nath & Kumar (2013) : Concluded that fly ash based geopolymers by adding GGBS and granulated corex slag as 0-50% by weight of fly ash, exhibited better enhancement in compressive strength of geopolymers with increase of slag content from 20 to 50%. Also granulated corex slag-fly ash based geopolymers showed better compressive strength than GGBS-fly ash based geopolymers at the age of 7 and 28 days due to the better formation of calcium silicate hydrate gel in the geopolymer matrix.

Amrul Kaish.A.B.M [15] et al. (2015) : Investigated “Axial behavior of ferrocement confined cylindrical concrete specimens with different sizes” by experimental studies. Each type of cylindrical specimens is confined with one or two layers of WWM ferrocement jacket having a constant thickness. Experimental studies show the effectiveness of ferrocement confinement in enhancing the strength, energy absorption and ductility capacity of concrete specimens.

3. MATERIALS USED

3.1 Cement

Cement used in this research is 53 grade Ordinary Portland cement and it was obtained from Ultra-Tech cements limited, Vijayawada, Andhra Pradesh, India. The specific gravity of cement was 3.17.

3.2 FA and GGBS

Low calcium FA and GGBS were used as source materials for producing geopolymer mortar. The specific gravity of fly ash is 2.21 and GGBS is 2.82. Both binder materials are kept in sun dried condition for 6 hours, then thoroughly mixed to achieve homogeneous mix, then this mixture was retained in an oven for 24 hours at 100^0C. The chemical composition of FA and GGBS are shown in Table 1.

Table 1: Chemical composition of Fly ash and GGBS

Chemical	Fly Ash (wt%)	GGBS (wt%)
SiO2	51.34	35.32
Al2O3	34.97	15.06
Fe2O3	3.711	0.334
MgO	0.552	8.6
CaO	4.798	35.04
Na2O	0.45	0.44
K2O	0.812	0.508
MnO	0.053	0.326
TiO2	1.361	0.813
LOI	1.953	3.559

3.3 Fine aggregate

Fine Aggregate (sand) used is clean dry river sand. Specific gravity of sand was found as 2.67 and fineness modulus was determined as 2.44. it confirms zone II of IS 383-1970 requirements.

3.4 Alkaline solution

The ratio of sodium silicate and sodium hydroxide (Na2SiO3/NaOH) was maintained as 2.5. Both solutions were obtained from local chemical suppliers. NaOH was purchased in flakes and it was dissolved in distilled water. Molarity of NaOH chosen as 12M. The alkaline solution was prepared 24 hours before to casting geopolymer mortar. Table 2 shows the mix proportion of GP mortar.

Table 2: Mix proportion of GP mortar

Cementitious material	Flyash (kg /m³)	GGBS (kg /m³)	Sand (kg/m³)	NaOH (kg /m³)	Na2SiO3 (kg /m³)	Alkaline Liquid (kg/m³)	Water (kg/m³)
F100	724.12	-	1086.20	82.76	206.89	289.65	72.41
G100	-	724.12	1086.20	82.76	206.89	289.65	72.41
F50G50	362.06	362.06	1086.20	82.76	206.89	289.65	72.41

3.5 Steel reinforcement

Fe500-12mm steel used as main reinforcement and 6mm steel used as laterial tiess in M25 RC column. EMM and WWM as shown in Figure 1 and 2 used as reinforcement in ferrogeopolymer mortar. Mechanical properties of steel bars and steel meshes are shown in Table 3 and 4.

Figure 1:
Expanded metal mesh (EMM)

Figure 2:
Welded wire mesh (WWM)

Table 3: Mechanical properties of steel bars

Type of Mesh	Diameter (mm)	Yield or Proof strength (MPa)	Ultimate Tensile strength (MPa)
Steel bar	6	329	478
	12	488	681

Table 4: Mechanical properties of meshes (adopted from the supplier)

Type of Mesh	Opening Size (mm)	Weight (gm/m^2)	Diameter (mm)	Yield Tensile strength (MPa)	Ultimate Tensile strength (MPa)	Modules of Elasticity (Gpa)
EMM	19*33	17	1.5*2.1	225	334	136
WWM	12*12	4.2	0.75	379	598	171

4. EXPERIMENTAL PROGRAM

This experimental program done in four phases as follows;

Phase 1: Made nine geopolymer mortar cubes (70.6mm*70.6mm*70.6mm), as shown in Table 5 the compressive strength values of GP mortar cubes.

Phase 2: Made one M25 grade RC square (150mm*150mm) column of height 1500mm than find the ultimate load of the column in experimental load testing, as shown in Table 6 mix proportion of M25 grade concrete and in Table 7 RC column details.

Phase 3: Again made same size of six M25 grade RC columns (150mm*150mm*1500mm), were subjected to 80% of the ultimate load.

Phase 4: Strengthened damaged six RC columns with ferro geopolymer jacketing of optimum mortar mix (F50G50), as shown in Table 8 jacketed column specimens. Jacketing was provided for columns full height with an end gap of 20 mm at both the ends to avoid direct loading on ferrogeopolymer mesh. As shown in Figure 3 column reinforcement details.

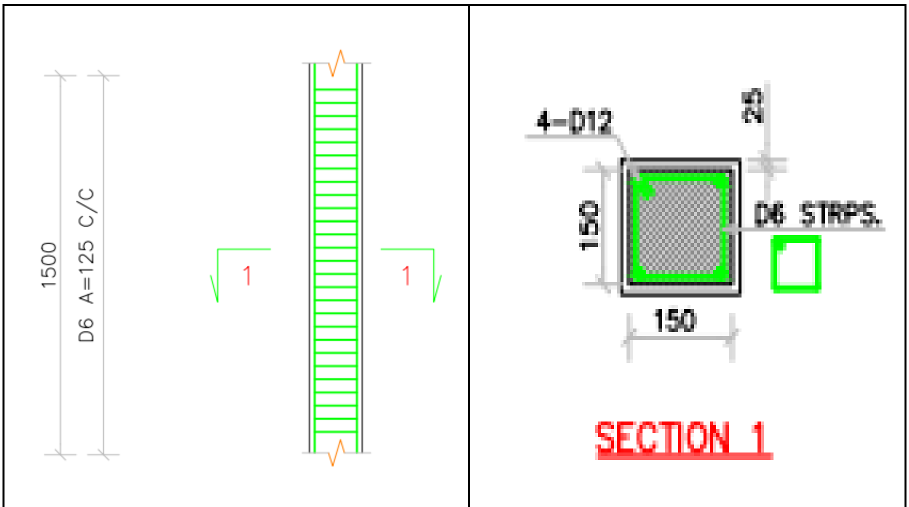

Figure 3: Column reinforcement details

Table 5: Compressive strength values of GP mortar cubes

Mix ID	Compressive Strength (Mpa)		
	7 Days	28 Days	90 Days
F100	25.76	39.66	42.88
G100	26.47	40.64	43.91
F50G50	29.77	45.72	46.19

F* = Fly ash and G* = Ground granulated blast furnace slag

Table 6: M25 Grade concrete mix proportion

Materials	Quantity
Cement	359 kg/m^3
Water	154 kg/m^3
Fine aggregate	740 kg/m^3
Coarse aggregate	1267 kg/m^3
Chemical admixture	3.53 kg/m^3
Water/cement ratio	0.43
M25 Mix proportion	1 : 2.06 : 3.52

Table 7: Details of RC column

Materials	Quantity
Grade of concrete	M25
Grade of steel	Fe500
Column size	150mm*150mm*1500mm
Area of column	22500mm^2
Area of main steel	452.38mm^2, 4bars-12mm dia
Laterial ties	6mm dia, 125mm c/c
Ultimate load	376.54kN
80% of ultimate load	301.23kN
Ultimate deflection	10.78mm
Deflection at first crack load	5.6mm
Ductility index	1.92

Table 8: Series of jacketed column specimens

Column ID	Description
FGE1	Jacketed columns with 1 layers of EWM FA&GGBS based GP mortar
FGE2	Jacketed columns with 2 layer of EWM FA&GGBS based GP mortar
FGE3	Jacketed columns with 3 layer of EWM FA&GGBS based GP mortar
FGW1	Jacketed columns with 1 layers of WWM FA&GGBS based GP mortar

FGW2	Jacketed columns with 2 layers of WWM FA&GGBS based GP mortar
FGW3	Jacketed columns with 3 layers of WWM FA&GGBS based GP mortar

5. RESULTS AND DISCUSSIONS

The behavior of the tested jacketed columns in terms of ultimate load, ultimate deflection, load–deflection relationship and failure mode, and cracking behavior are discussed as follows.

5.1 RC column

Reinforced concrete column showed sudden failure with an explosive sound by bursting of concrete and failed by splitting of concrete. As the load reached ultimate value the column failed in compression, mainly due to the unstable propagation of internal micro cracks. The ultimate load of the RC column was 376.54kN and ultimate deflection was 10.78mm.

5.2 Jacketed column (JC)

Ultimate load values of jacketed tested columns are shown in Figure 4 and Table 9. All jacketed columns (FGE1 to FGW3) shows higher ultimate load carrying capacity than RC column was 16.91%, 26.50%, 40.89%, 9.72%, 21.67% and 33.62%. As the load started, some small cracking sounds were heard in jacketed columns due to micro cracking of GP mortar. As the load reached the ultimate value, jacketed columns failed in compression and spalling GP mortar layer was observed. Figure 5 and Table 9 shows the ultimate deflection of jacketed tested columns. All jacketed columns (FGE1 to FGW3) shows higher ultimate deflection than RC column was 11.68%, 19.57%, 2.78%, 17.25%, 22.26% and 11.41% and also shows higher ductility index was 64.58%, 55.20%, 10.93%, 68.75%, 55.72% and 19.79% The columns FGE1, FGE2 and FGE3 showed better results in both load carrying capacity and deflection than FGW1, FGW2 and FGW3 respectively. The columns FGW1, FGW2 and FGW3 showed better ductility index than the columns FGE1, FGE2 and FGE3 respectively. Among all the jacketed columns FGE3 show higher ultimate load capacity and less deflection with low ductility index and FGW1 show less ultimate failure load and high ductility index.

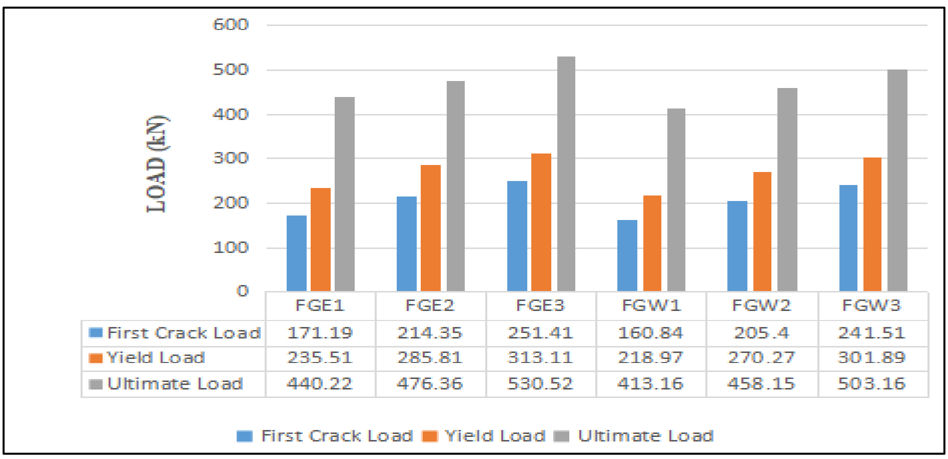

Figure 4: Ultimate load values of jacketed columns

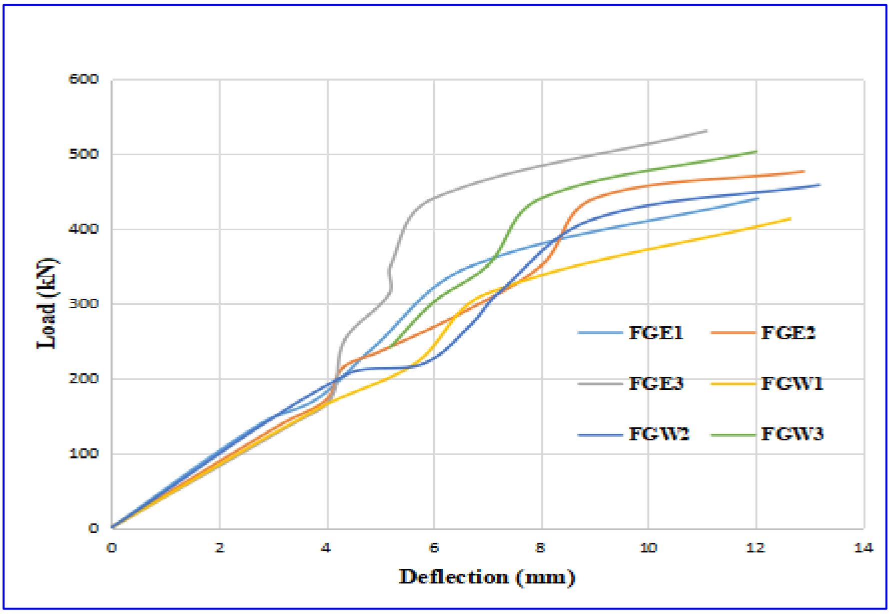

Figure 5: Ultimate deflections of jacketed columns

Table 9: Experimental test results

Column ID	First crack		Yield		Ultimate		Ductility index
	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)	
FGE1	171.19	3.81	235.51	4.80	440.22	12.04	3.16
FGE2	214.35	4.32	285.81	6.49	476.36	12.89	2.98
FGE3	251.41	4.35	313.11	5.18	530.52	11.08	2.13
FGW1	160.84	3.90	218.97	5.65	413.16	12.64	3.24
FGW2	205.40	4.40	270.27	6.68	458.15	13.18	2.99
FGW3	241.51	5.20	301.89	6.01	503.16	12.01	2.30

6. COMPARISON BETWEEN EXPERIMENTAL AND THEORETICAL RESULTS

The advantage of ferrogeopolymer jacket column compare to RC column is higher ductility due to the confinement of steel mesh composite with GP mortar. For ultimate load capacity in theoretical analysis use basic equations of Egyptian and American codes.

Basic Egyptian Code (ECP) Equation [3]

Pu = 0.35 Ac fcu + 0.67 As fy ……………(1)

Basic ACI 318 Code Equation [2]

Pu =0.85 Ac fcu + As fy ……………………(2)

To study and know the significant improvement in static strength of all jacketed specimens, these equations were modified according to [2] and [3] to be as follows:

Modified Egyptian Code (ECP) Equation

Pu = 0.35 Ac fcu + 0.67 As fy + 0.95 Acf fGPf + Asf N fsf …………(3)

Modified ACI 318 Code Equations

Pu = 0.85 Ac fcu + As fy + 0.85 Acf fGPf + Asf N fsf ………..(4)

Where:

Pu = Ultimate load capacity of column

fcu = Concrete compressive strength

fGPf = Compressive strength of GP mortar

fy = Yield strength of steel bars

Ac = Gross area of concrete

Acf = Area of cement mortar

Asf = Area of additional steel

N = Number of wire mesh layers

fsf = tensile strength of wire mesh

As = Area of main steel

The ratio of experimental to theoretical (PUexp / PUth) results are shown in Table 10. The results obtained from modified ACI code are underestimated for six jacketed columns while results obtained from modified ECP code are underestimated for four columns FGE1, FGE2, FGW1 and FGW2 and overestimated for two columns FGE3 and FGW3.

Table 10: Comparison between experimental and theoretical results

Column ID	Ultimate load Experimental Puexp	Ultimate load Modified ACI 318 Code Puth	Ultimate load Modified Egyptian Code (ECP) Puth	PUexp / PUth Modified ACI	PUexp / PUth Modified ECP
FGE1	440.22	898.41	565.31	0.49	0.77
FGE2	476.36	898.81	565.70	0.53	0.84
FGE3	530.52	899.20	566.10	0.59	0.93
FGW1	413.16	898.18	565.08	0.46	0.73
FGW2	458.15	898.35	565.24	0.51	0.81
FGW3	503.16	898.51	565.41	0.56	0.88

7. CONCLUSION

Based on experimental test results, observations and discussions following points can be drawn about the "Behaviour Of Damaged Concrete Columns Confined By Ferro Geopolymer Jacket In Axial Compression."

- The confinement with Ferro geopolymer jacket technique in damaged reinforced concrete columns improve the strength and ductility.
- Six jacketed columns showed higher ultimate failure load, higher deflections and high ductility index than RC column.
- The columns jacketed by 1, 2 and 3 layers of expanded metal mesh obtained higher ultimate failure load and deflections than columns jacketed by 1, 2 and 3 layers of welded wire mesh respectively.
- The columns jacketed by 1, 2 and 3 layers of welded wire mesh obtained higher ductility index than columns jacketed by 1, 2 and 3 layers of expanded metal mesh respectively.
- Column jacketed by one layer of steel mesh obtained highest ductility index value than reinforced with two and three layers of steel mesh.
- The column jacketed by three layers of expanded metal mesh obtained highest ultimate failure load, less deflection and low ductility index.
- The column jacketed by three layers of welded wire mesh obtained smallest ultimate failure load and highest ductility index.
- As applied load reached the ultimate failure load, six jacketed columns are failed in compression mode.
- From the comparison of experimentally and theoretical results, that results obtained from modified ACI code are underestimated for columns jacketed by 1, 2 and 3 layers of expanded wire mesh and welded wire mesh.
- And also the results obtained from modified ECP code underestimated for columns jacketed by 1, 2 and 3 layers of expanded wire mesh and welded wire mesh.
- By changing and adjusting the modified ECP code and ACI code equations theoretical values to be more agreement with experimental values.

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Conflicts of Interest

The author declares no conflict of interest.

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