

NUMERICAL STUDY OF SHEAR BEHAVIOR OF GEOPOLYMER CONCRETE BEAM WITHOUT STIRRUPS

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Abstract

The need to develop the concrete industry has increased with the increase in environmental damage resulting from building and construction operations. In the present research, the Numerical study of shear behavior of geopolymer concrete beams without stirrups by using the ANSYS program. It also includes concrete modelling to study the behavior of geopolymer concrete (GPC). The longitudinal reinforcements of beams (without stirrups) were "basalt fiber reinforced polymer bars". In order to enhance the shear behavior of the specimens, various types of fibers were added to geopolymer concrete (GPC): "steel fibers (SF), synthetic polypropylene fibers (PF), polyvinyl alcohol fibers (PVF), and carbon fibers (CF)". A numerical analysis was performed by the ANSYS version 15 program to study many parameters affecting the shear behavior of geopolymer concrete, such as longitudinal reinforcements, , and the inclusion of the opening. The results indicated that using steel fibers (SF) in geopolymer concrete increased the load failure of the tested specimens. On the other hand, using carbon fibers (CF) in the geopolymer concrete enhanced the ductility factor of these beams. The load capacity of the geopolymer concrete specimen is enhanced with longitudinal reinforcement by the CFRP bar compared to those reinforcements by BFRP bars. While the use of GFRP bars was less efficient than BFRP bars. Using FRP bars, and steel bars in strengthening geopolymer concrete beams with openings enhanced the failure load of these specimens.

Keywords:

Geopolymer concrete beam (GPC);
Shear behaviour;
Basalt fiber bars (BFRP);
Numerical Study;
Hybrid fiber.

1 Introduction

Recently, geopolymer concrete (GPC) (slag-containing) was introduced to replace ordinary Portland concrete (OPC) to decrease the harmful effects of concrete on the world [1,2]. Replacing ordinary Portland concrete with geopolymer concrete reduces carbon dioxide emissions [3]. Research has shown a high bond between steel reinforcements and GPC [4]. Bakharev T [5] showed that the geopolymer concrete is better than ordinary Portland concrete in resisting acids. Nath P's study [6] also showed that the OPC is characterized by its high flexural resistance. Recently, much research has been conducted on measuring the fresh material properties of GPC [7,8]. E.I. Diaz et al [9] also researched to investigate the physical and mechanical properties of the components of GPC. X.J. Song et al. [10] studied the durability of GPC with fly ash against sulphuric acid attack. Also, M. Albitar et al. [11] tested the durability of GPC prepared using "Class-F fly ash or blended fly ash and granulated lead smelter slag (GLSS)". Parthiban Kathirvel et al. [12] studied the effect of using recycled aggregate in preparing GPC. The results showed that the failure load of GPC improved by using recycled aggregate.

However, research on the structural behavior of "GPC" elements under shear is limited. Visintin [13] investigated the shear behavior of "GPC" beams without stirrups. Visintin et al. [13] tested eight specimens. The tests show agreement in the shear-friction properties of geopolymer concrete and OPC. Kim Hung et al. [14] study the structural behavior and "mechanical properties" of lightweight aggregate geopolymer concrete with steel fibre. The use of these fibers improved the "mechanical properties" of geopolymer concrete. Also, Tian et al. [15] tested the geopolymer concrete beams with steel fibre

subject to shear. Pattanapong et al. [16] tested eight concrete beams to compare the behavior of "OPC" and "GPC" beams. "GPC" beams failed in bending, while "OPC" beams failed in shear.

Tung T. Tran et al. [17] investigated of performance of shear behavior of "geopolymer concrete beams" with various types of fibers. Thirteen specimens with 150X200 mm dimensions were tested. The reinforcement of specimens was basalt FRP (BFRP). The tests exhibited that the use of steel fibers improves the shear capacity of specimens. Ali et al. [18] performed a numerical analysis to study the structural behavior of "geopolymer concrete beams". The tests showed that cracks formed earlier in "GPC beams" than in "OPC" beam. Mohamad A Hasan et al. [19] tested six "reinforced geopolymer concrete" T-beams with Glass FRP to compare the structural behavior of "OPC" and "GPC" T-beams. Venkatachalam et al. [20] conducted laboratory and analytical tests to obtain the best modeling of geopolymer concrete using the "ANSYS program". Pham [21] also verified the structural behavior of "GPC" beams by conducting a laboratory and analytical study.

Strauss et al [22], Valašík et al [23], and Wu et al [24] used stochastic modelling for numerical analysis to study the structural behavior of concrete elements. Kozielova [25] modeled the behaviour of the RC slab with the subsoil using the "Newton-Rabson method". The results showed the change in stiffness after cracks occurred.

The current work aims to propose a non-linear study to optimize the modeling of the structural behavior of beams without stirrups. A verification was made with the experimental specimens produced by Tung T. Tran et al. [17] by using Ansys 15 to evaluate the structural behavior of geopolymer concrete beams with various types of fibers.

2 Research significance

This research aims to reach the best modeling for geopolymer concrete beams and simulate their structural behavior by comparing analytical specimens with laboratory specimens. The analyzed beam models had the same geometry, and reinforcement as those of the experimental specimens presented by Tung T. Tran et al. [17].

More beams were modeled using ANSYS software to study more parameters that affect the structural behavior of geopolymer beams to obtain the best simulation of these beams.

Tung T. Tran 's experimental program [17] includes testing of thirteen "GPC" beams subjected to line load at the mid-span. Thirteen beams have been tested, which include various types of fiber. The reinforcement of beams was basalt FRP (BFRP) with an ultimate tensile stress of 1200 MPa. Table 1 shows fibre volume of these specimens. Specimen details and test setup are shown in Figure 1.

Table 1: Fiber volume fraction of all the beams [17].

Beam	Fiber volume fraction (%)			
	Steel	Synthetic	PVA	Carbon
OPC	–	–	–	–
OPC-0.5SF	0.5	–	–	–
GPC1	–	–	–	–
GPC2	–	–	–	–
GPC-0.25SF	0.25	–	–	–
GPC-0.5SF	0.5	–	–	–
GPC-1SF	1	–	–	–
GPC-0.25PF	–	0.25	–	–
GPC-0.5PF	–	0.5	–	–
GPC-0.4SF-0.1PVF	0.4	–	0.1	–
GPC-0.3SF-0.2PVF	0.3	–	0.2	–
GPC-0.4PF-0.1CF	–	0.4	–	0.1
GPC-0.3PF-0.2CF	–	0.3	–	0.2

Tung et al. [17] used two mixtures to cast the beams. Table 2 shows the proportion of the two mixtures, where all specimens used Mixture 1 except "GPC2" and "GPC-1SF" used Mixture 2.

Table 2: Mix proportion of "GPC" (kg/m³) [17].

Compositions	FA	GGBFS	Aggregates		NaOH Solution	Na ₂ SiO ₃ solution
			Crushed stone	Sand		
Mixture 1	300	100	1100	630	69	172
Mixture 2	240	160	1100	630	69	172

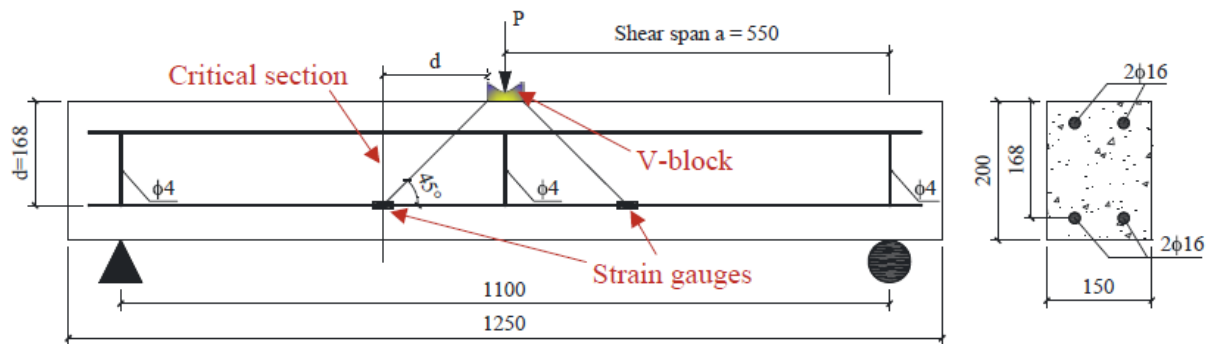


Fig. 1: Specimen details and test setup [17].

3 Methodology and analytical model

Twenty-six tested specimens were modeled by the ANSYS program to analyze the results of Tung T. Tran's study [17] and performed a parametric study. ANSYS modeled Geopolymer concrete using "SOLID 65 element" with 6 faces and 8 nodes, Figure 2. This element can crush in compression, crack in tension, and behave nonlinearly. ANSYS defined Geopolymer concrete as a multi-linear behavior material, Table 3.

Table 3: Modeling of used Concrete in ANSYS.

Material	Element Type	Material Properties	
Concrete	Solid65	Linear Isotropic	
		Modulus of elasticity (EX) (N/mm ²)	4400 (fcu) ^{0.6}
		Poisson ratio (PRXY)	0.26
		Concrete Properties	
		Open Shear-Coefficient	0.3
		Closed Shear-Coefficient	0.8
		Uniaxial Cracking Stress (fctr) (N/mm ²)	0.6 (fcu) ^{0.6}
		Uniaxial Crushing Stress (f' _c) (N/mm ²)	0.8 fcu
		Multi-Linear Isotropic	
		Strain	Stress (MPa)
		from cube testing	from cube testing

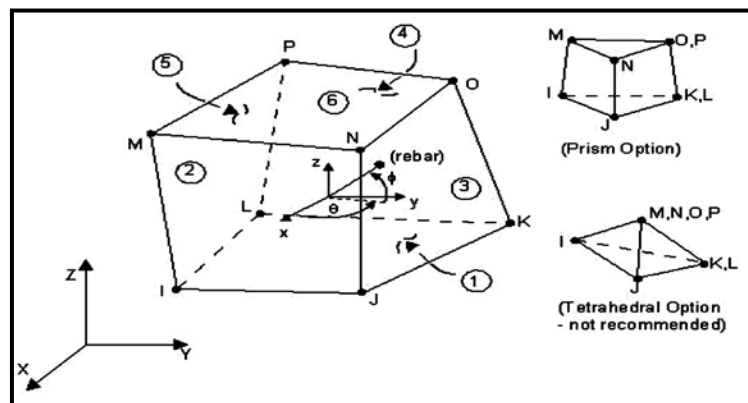


Fig. 2: "SOLID 65 element" [26].

ANSYS modeled FRP rebar, and Steel rebar using a uniaxial compression-tension element "(LINK180 element)" with 2 nodes and 3 degrees of freedom, Figure 3. Table 4 shows material properties for FRP rebar and Steel rebar.

ANSYS modeled Load plate and supports using "SOLID 45 element" with 8 nodes and 3 degrees of freedom, Figure 4.

Table 4: Material properties for FRP rebar and steel rebar.

Material Properties		steel rebar	BFRB rebar	CFRB rebar	GFRB rebar
Linear Isotropic	Modulus of elasticity (EX) (N/mm ²)	200000	55000	148000	40000
	Poisson's ratio (PRXY)	0.3	0.2	0.135	0.3
Bilinear Isotropic	Yield Stress (fy) (N/mm ²)	360	1200	2000	735
	Tan Modulus (N/mm ²)	0	0	0	0

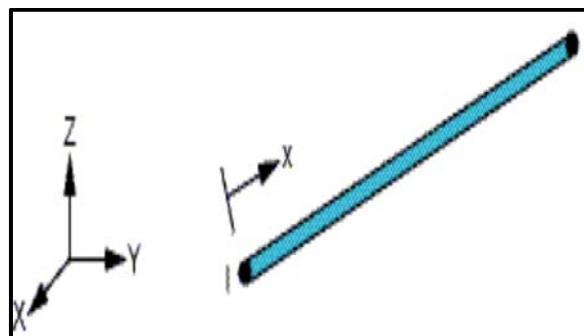


Fig. 3: "LINK180 element" [26].

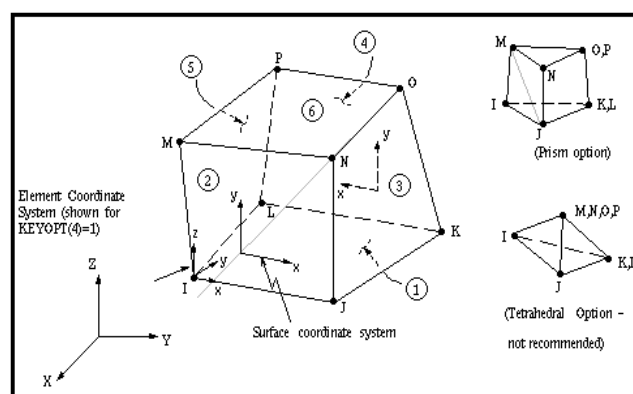


Fig. 4: "SOLID 45 element" [26].

In this research, the concentrated load was applied by using transverse roller in the y direction. Hinged and roller supports (two supports) in the beam model as shown in Figure 5.

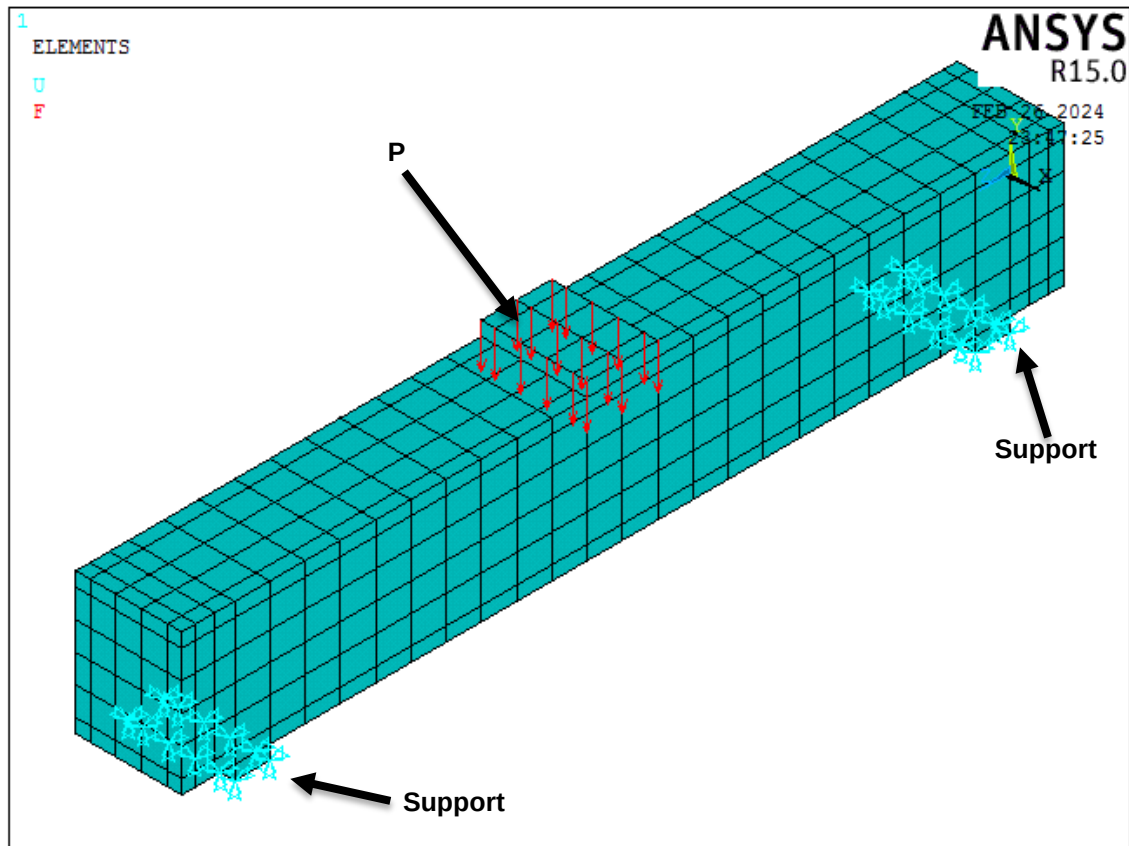


Fig. 5: Beam model in ANSYS.

4 Validation of analytical model

The ANSYS results were compared with the Laboratory results conducted by Tung T. Tran et al. [17]. ANSYS models provided good results showing the structural behavior of the geopolymers concrete beams.

4.1 Crack patterns

The shear crack of the analytical Beams were observed in Figure 6. Where shear cracks appear along with flexural cracks. The failure occurred diagonally at the mid span of the beams “diagonal tension failure” [27].

The results show a lot of flexural shear cracks before crushing concrete in beams with steel fiber, because SF transfers tension stress across shear cracks [28]. Also, beams with “synthetic polypropylene fibers” have lower flexural-shear cracks and inclined cracks than Beams with steel fiber.

Beams reinforced with SF and PVF showed a greater number of cracks compared to specimens reinforced with PVF and CF, which indicates the effectiveness of the SF and PVF hybrid in resisting cracks.

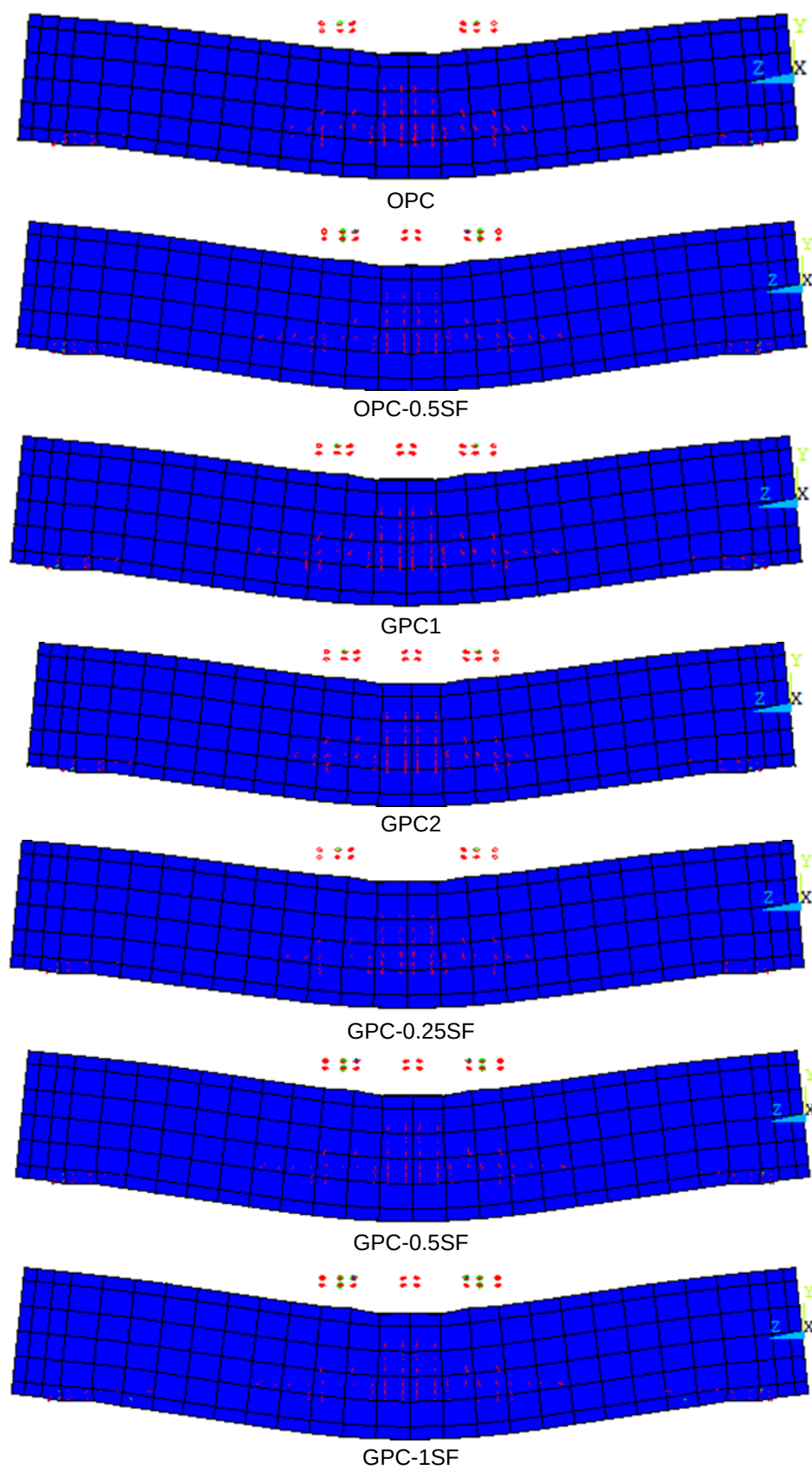


Fig. 6: Crack patterns for Specimens OPC, OPC-0.5SF, GPC1, GPC2, GPC-0.25SF, GPC-0.5SF, and GPC-1SF.

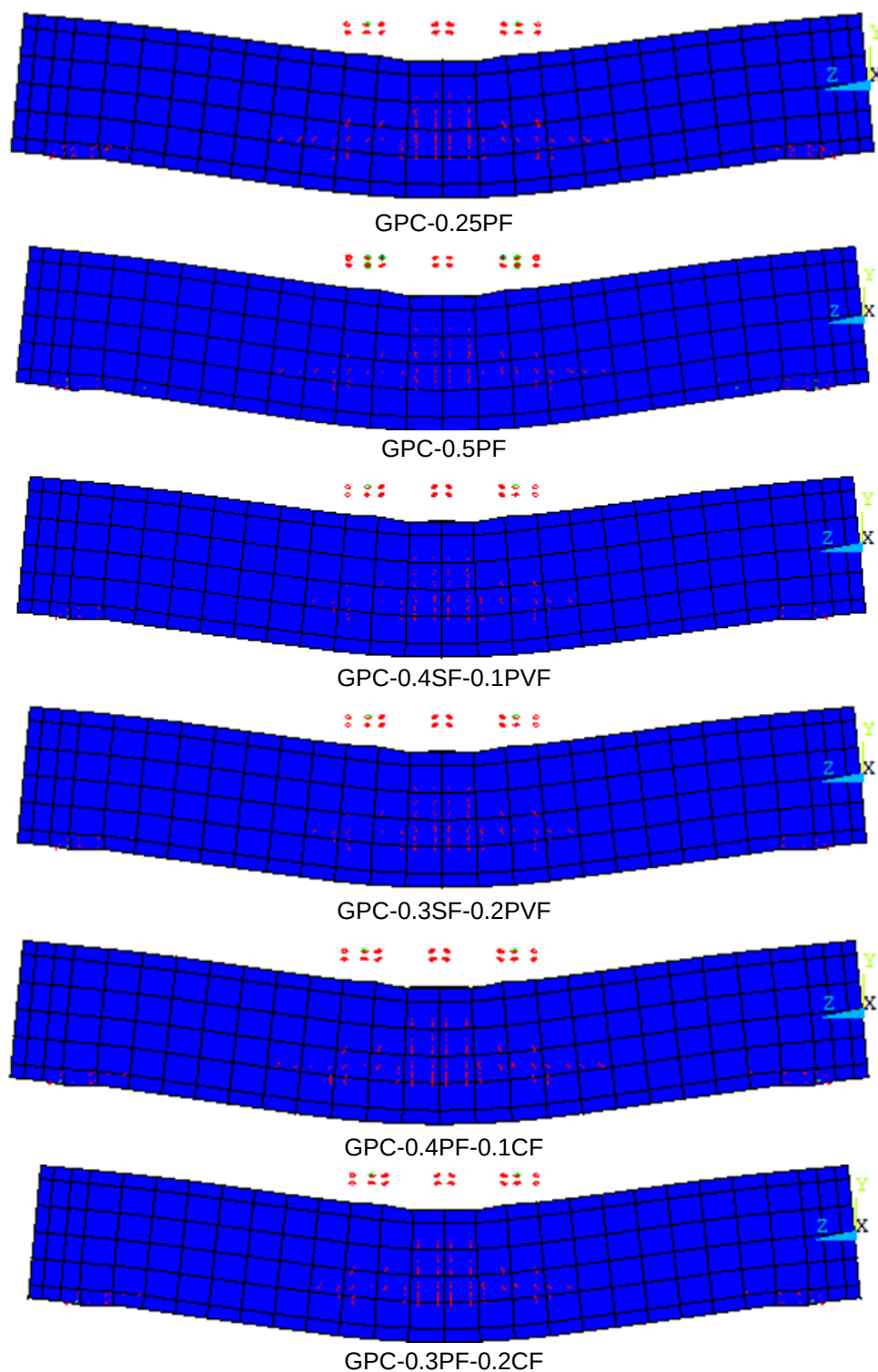


Fig. 7: Crack patterns for Specimens GPC-0.25PF, GPC-0.5PF, GPC-0.4SF-0.1PVF, GPC-0.3SF-0.2PVF, GPC-0.4PF-0.1CF, and GPC-0.3PF-0.2CF.

4.2 Failure load and maximum central deflection

The experimental results of Tung T. Tran [17] were compared with the analytical results, Tables 5 and 6.

The analytical results showed an increase of 8.3% for the failure load and a decrease of 8.7% for the central deflection values compared to those obtained experimentally. Figure 8 to 11 show the deflection results for these beams. The curves show the linear behavior of these beams from when the load is applied until the appearance of cracks, where their behavior becomes non-linear until failure.

Beam GPC-1SF have the highest failure load. Therefore, using steel fibers (SF) in geopolymer concrete increases the load capacity of GPC beams due to the high tensile strength of steel fibers (SF).

On the other hand, PF showed less effectiveness in shear strength compared to SF due to the decrease in tension strength of PF.

Table 5: The results of the loads capacity.

Specimen	Failure load [kN]		% Difference	Strains for FRP
	Proposed	Experimental		
OPC	45	42	7.14	0.0191
OPC-0.5SF	48.25	47.6	1.37	0.0198
GPC1	34.25	32.1	6.70	0.0184
GPC2	37	35.1	5.41	0.0188
GPC-0.25SF	33.5	31.7	5.68	0.0181
GPC-0.5SF	53.25	50.6	5.24	0.0242
GPC-1SF	57.5	53.5	7.48	0.0251
GPC-0.25PF	30	27.7	8.30	0.0177
GPC-0.5PF	42.25	40	5.63	0.0195
GPC-0.4SF-0.1PVF	38	37.3	1.88	0.0180
GPC-0.3SF-0.2PVF	45.25	43	5.23	0.0235
GPC-0.4PF-0.1CF	31.5	29.3	7.51	0.0175
GPC-0.3PF-0.2CF	30.75	28.7	7.14	0.0177

Table 6: The results of the maximum deflection at failure.

Specimen	Maximum central deflection [mm]		% Difference
	Proposed	Experimental	
OPC	9.8	10.4	-5.77
OPC-0.5SF	7.8	8.3	-6.02
GPC1	8	8.2	-2.44
GPC2	8.6	9	-4.44
GPC-0.25SF	5.7	6	-5.00
GPC-0.5SF	10.3	10.8	-4.63
GPC-1SF	8.6	9.4	-8.51
GPC-0.25PF	6.2	6.4	-3.13
GPC-0.5PF	9.6	10.1	-4.95
GPC-0.4SF-0.1PVF	6.3	6.9	-8.70
GPC-0.3SF-0.2PVF	8.1	8.8	-7.95
GPC-0.4PF-0.1CF	7	7.2	-2.78
GPC-0.3PF-0.2CF	8.1	8.3	-2.41

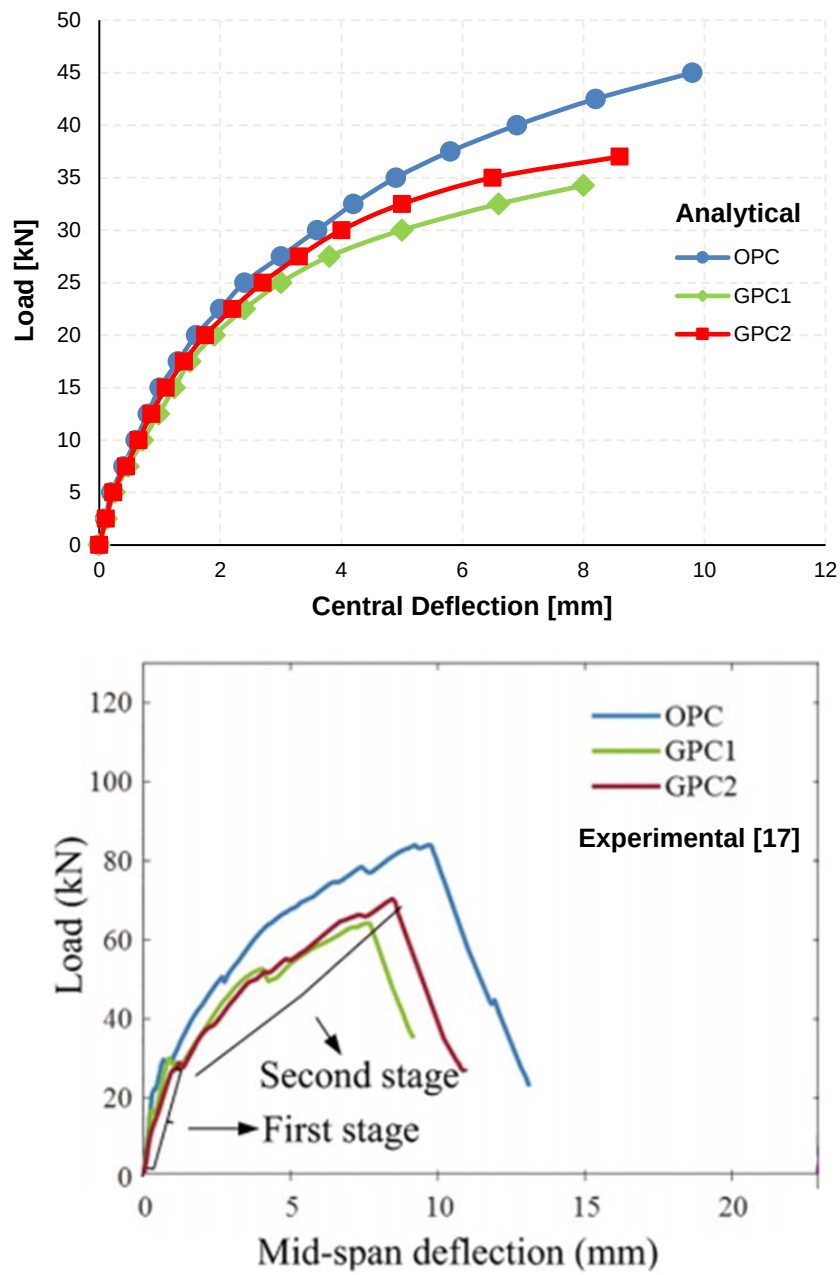


Fig. 8: Load–deflection curve of specimens OPC, GPC1, and GPC2.

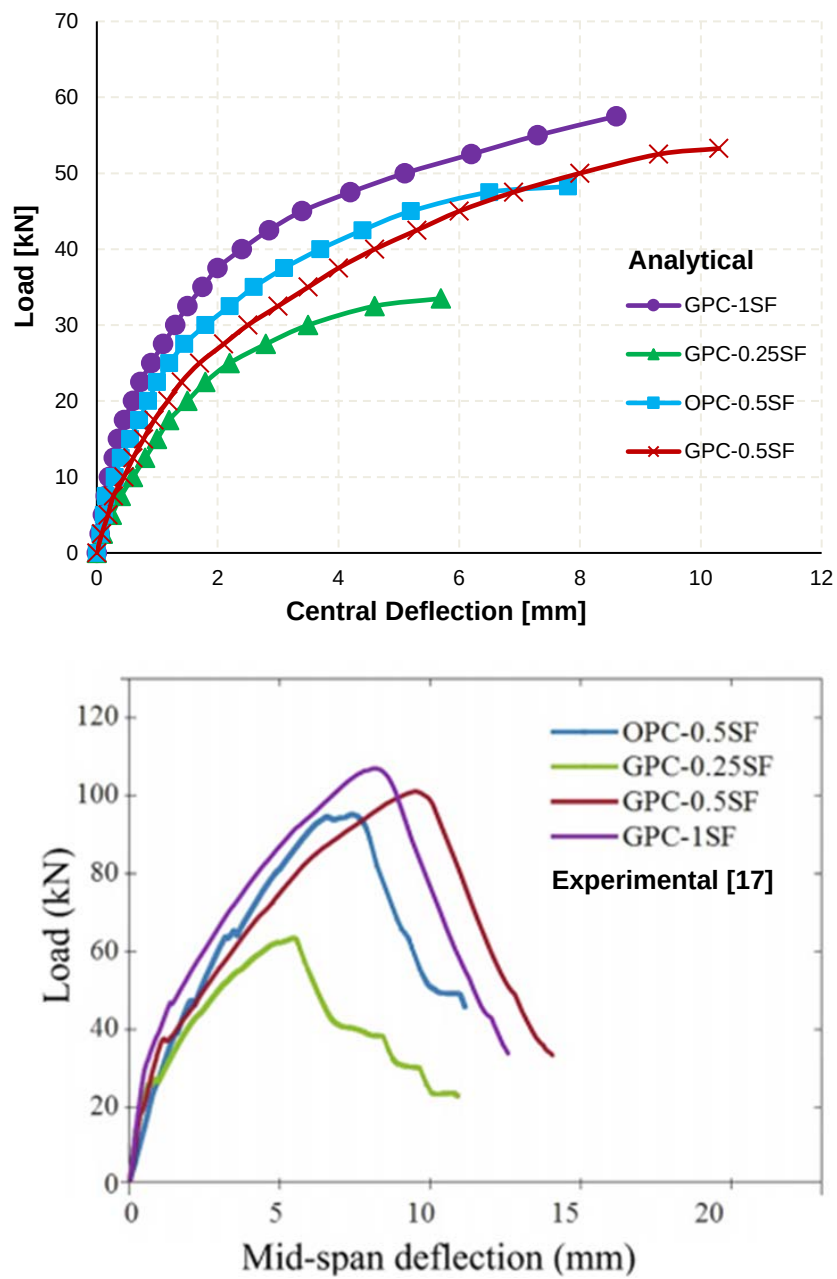


Fig. 9: Load–deflection curve of specimens OPC-0.5SF, GPC-0.25SF, GPC-0.5SF, and GPC-1SF.

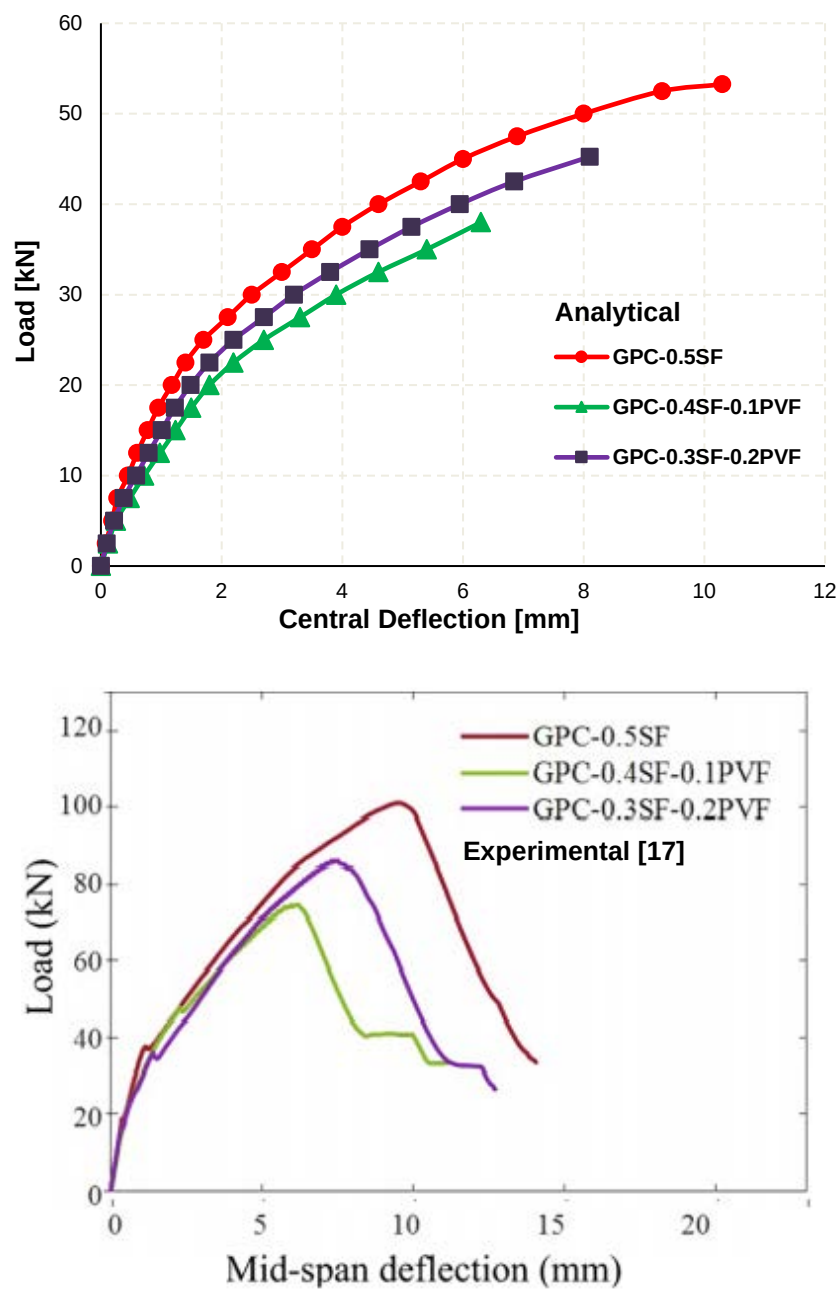


Fig. 10: Load–deflection curve of specimens GPC-0.5SF, GPC-0.4SF-0.1PVF, and GPC-0.3SF-0.2PVF.

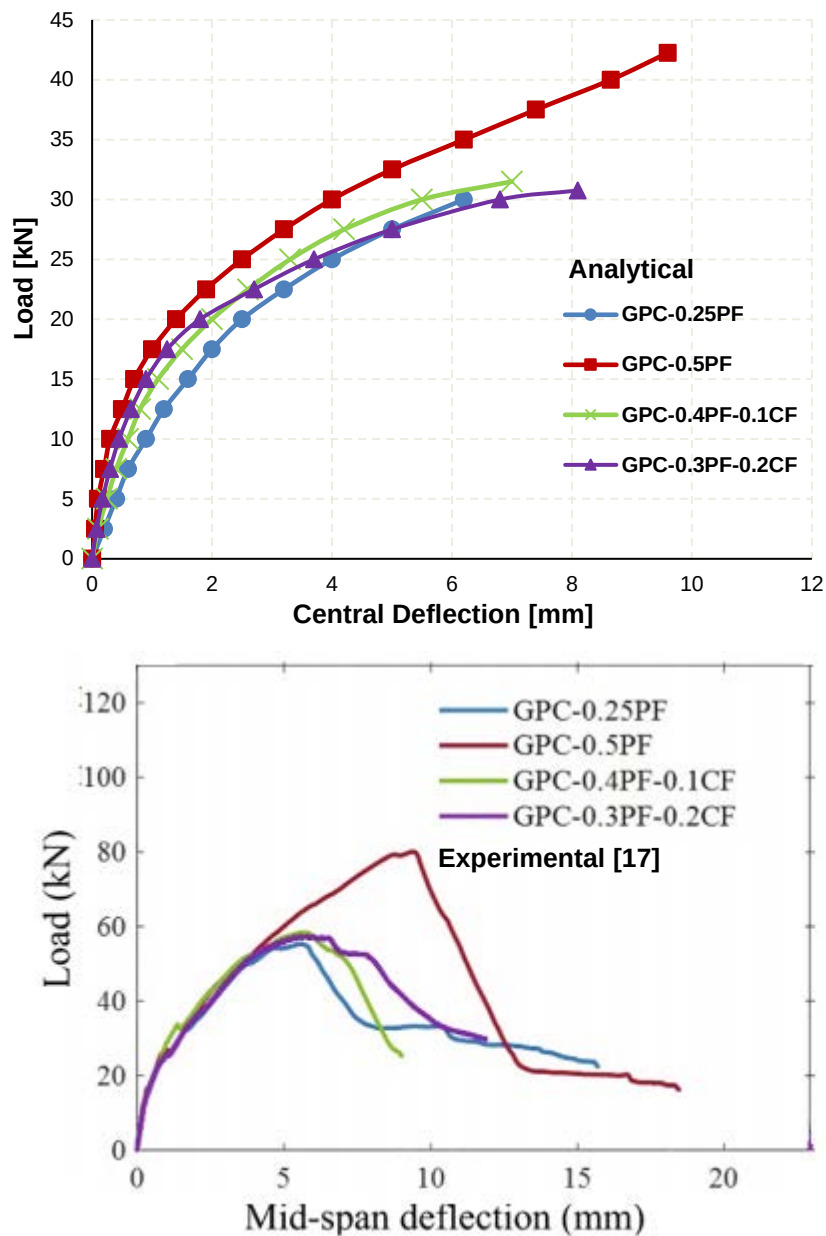


Fig. 11: Load–deflection curve of specimens GPC-0.25PF, GPC-0.5PF, GPC-0.4PF-0.1CF, and GPC-0.2PF-0.2CF.

4.3 Ductility

The area enclosed by the load-deflection curve represents the scale of ductility of these specimens. The ratio of maximum deflection to yield displacement defines the ductility factor. The comparison the ductility factor is shown in Table 7. The analytical results showed a reduction of 5.5 % for the ductility factor values compared to those obtained experimentally by Tung T. Tran [17]. Beam GPC-0.3PF-0.2CF have the highest ductility factor.

Therefore, using carbon fibers (CF) in geopolymer concrete increases the ductility factor of GPC beams.

Table 7: The results of the ductility factor.

Specimen	Ductility Factor		% Difference
	Proposed	Experimental	
OPC	1.02	1.07	-4.67
OPC-0.5SF	1.08	1.14	-5.26
GPC1	1.06	1.08	-1.85
GPC2	1.03	1.06	-2.83
GPC-0.25SF	1.03	1.09	-5.50
GPC-0.5SF	1.09	1.14	-4.39
GPC-1SF	1.11	1.15	-3.48
GPC-0.25PF	1.12	1.16	-3.45
GPC-0.5PF	1.05	1.07	-1.87
GPC-0.4SF-0.1PVF	1.08	1.13	-4.42
GPC-0.3SF-0.2PVF	1.15	1.17	-1.71
GPC-0.4PF-0.1CF	1.22	1.29	-5.43
GPC-0.3PF-0.2CF	1.49	1.54	-3.25

5 Parametric Study

To better understand the structural behavior of GPC beams without stirrups, a numerical analysis was performed by the ANSYS version 15 program to study an extensive parametric study. Table 8 shows the layout of the parameters.

The parameters were investigated namely: longitudinal RFT, fiber (SF & PF) volume fraction of the beams, and the existence of opening.

Table 8: Layout of the parameters.

Specimens	Group	Parameter under study	Longitudinal RFT	Steel fibers (SF)	Synthetic polypropylene fibers (PF)	RFT around the opening
GPC-0.5SF	A	longitudinal RFT	4Ø16 BFRP	0.5	-	-
GPC-GFRP			4Ø16 GFRP			
GPC-CFRP			4Ø16CFRP			
GPC-Ø12			4Ø12 BFRP			
GPC-Ø18			4Ø18 BFRP			
GPC-0.5SF	B	steel fibers (SF)	4Ø16 BFRP	0.5	-	-
GPC-1SF				1		
GPC-1.5SF				1.5		
GPC-2SF				2		
GPC-0.5PF	C	synthetic polypropylene fibers (PF)	4Ø16 BFRP	-	0.5	-
GPC-1PF					1	
GPC-1.5PF					1.5	
GPC-2PF					2	
GPC-0.5SF	D	Solid versus opening	4Ø16 BFRP	0.5	-	-
GPC-OS						2Ø10 S
GPC-OG						2Ø10 GFRF
GPC-OC						2Ø10 CFRF
GPC-OB						2Ø10 BFRF

5.1 Effect of longitudinal RFT

To better understand the impact of longitudinal Reinforcements on the structural behavior of geopolymer concrete beams without stirrups, five GPC beams with variable longitudinal RFT were modeled. The fibers content is equal in all specimens.

Specimen GPC-CFRP (reinforced by 4Ø16 Carbon FRP), Beam GPC-0.5SF (reinforced by 4Ø16 Basalt FRP) had higher loads capacity than Specimen GPC-GFRP (reinforced by 4Ø16 Glass FRP), by 24.3%, and 9.8%, respectively. Using CFRP bars to reinforce geopolymer concrete increases the load capacity of GPC beams due to the high tensile strength of carbon FRP. The specimens reinforced with basalt performed better than those reinforced with glass bars, Figure 12.

Specimen GPC-Ø18 (reinforced by 4Ø18 Basalt FRP), Beam GPC-0.5SF (reinforced by 4Ø16 Basalt FRP) had higher loads capacity than Specimen GPC-Ø12 (reinforced by 4Ø12 Basalt FRP), by 27.3%, and 16.4 %, respectively. It is observed that increasing the diameter of the longitudinal reinforcements increases the beam's load capacity.

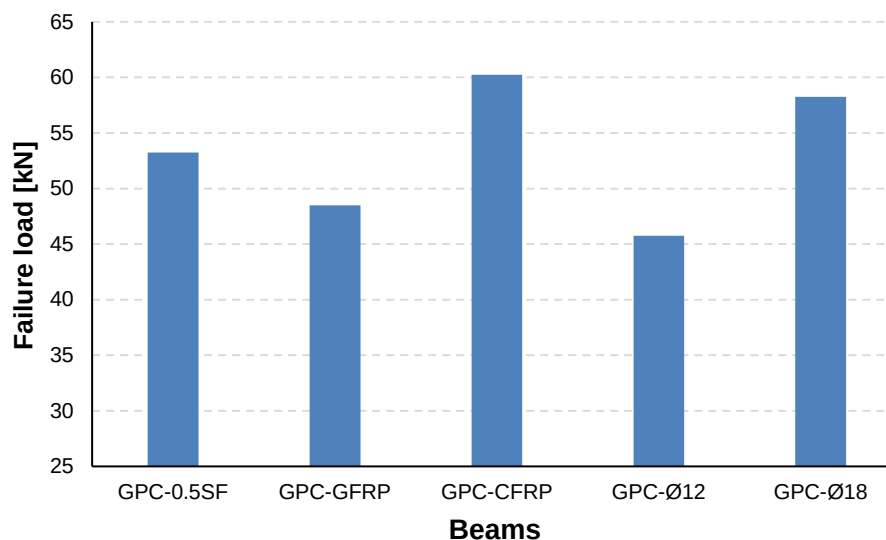


Fig. 12: Load capacity for specimens with different longitudinal RFT.

5.2 Effect of steel fibers (SF) content

The use of steel fibers (SF) in the geopolymer concrete improves the compressive strength f_{cu} . To better understand the impact of steel fibers (SF) content on the structural behavior of GPC specimens, four specimens with variable volumes of steel fibers (SF) were analyzed. These beams reinforced by 4Ø16 BFRP.

Specimen GPC-0.5SF, Specimen GPC-1SF, and Specimen GPC-1.5SF had higher loads capacity than Specimen GPC-2SF, by 1.3%, 9.4%, and 7%, respectively, Figure 13.

The results show that using "steel fiber (SF)" improved the shear behavior of these beams due to the bond strength of SF and geopolymer mortar. It is also preferable that the steel fiber (SF) content does not exceed 1% of the beam so as not to affect the workability of the geopolymer concrete mixture.

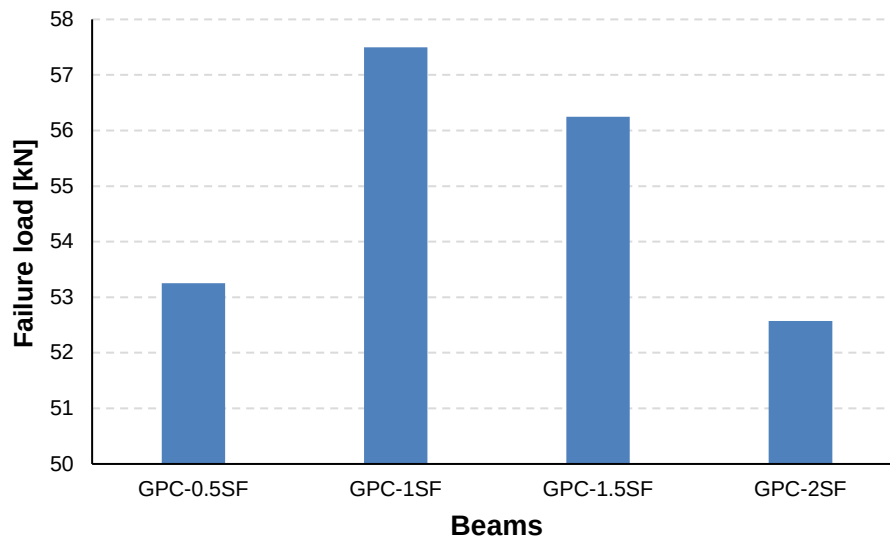


Fig. 13: Load capacity for beams with variable steel fiber content.

5.3 Effect of synthetic polypropylene fibers (PF) content

The use of synthetic polypropylene fibers (PF) in the geopolymer concrete improves the compressive strength f_{cu} . To better understand the effect of synthetic polypropylene fibers (PF) content on the structural behavior of GPC beams, four specimens with variable volumes of synthetic polypropylene fibers (PF) were analyzed. These beams reinforced by 4Ø16 BFRP.

Specimen GPC-0.5PF, Specimen GPC-1PF, and Specimen GPC-1.5PF had higher loads capacity than Specimen GPC-2PF, by 1.9%, 20.5%, and 11.5%, respectively, Figure 14. The results show that the use of PF improves the structural behavior of the beams due to the bond strength of PF and geopolymer mortar.

It is also preferable that the synthetic polypropylene fibers (PF) content does not exceed 1% of the beam so as not to affect the workability of the geopolymer concrete mixture.

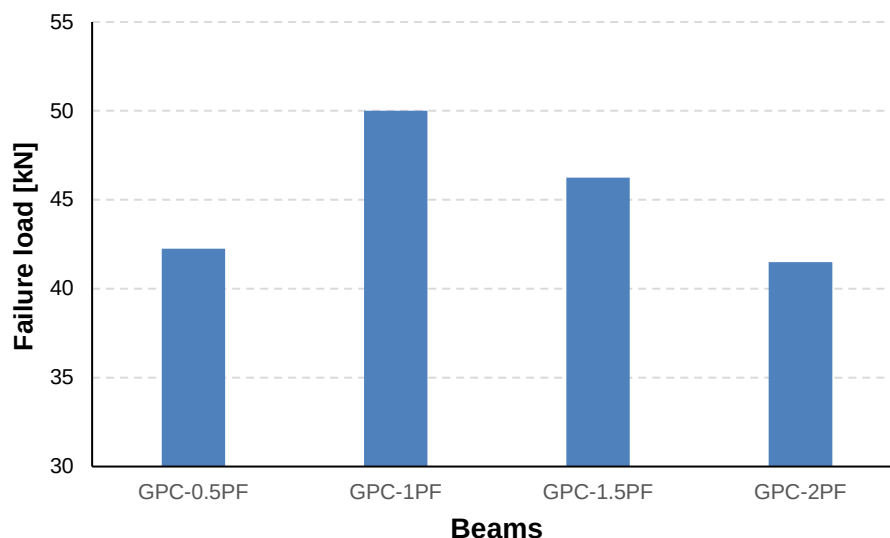


Fig. 14: Load capacity for beams with variable synthetic polypropylene fibers content.

5.4 Effect of the existence of opening

To better understand how the presence of openings affects the structural behavior of geopolymer concrete beams without stirrups, four GPC beams with central opening 300 x 100 mm were modelled, Figure 15. The fibers content is equal in all specimens.

Specimen GPC-0.5SF "without opening", Specimen GPC-OC "reinforced with 2Ø10 CFRP on the perimeter of the opening", Specimen GPC-OB "reinforced with 2Ø10 BFRP on the perimeter of the opening", and Specimen GPC-OG "reinforced with 2Ø10 GFRP on the perimeter of the opening" had higher loads capacity than Specimen GPC-OS "reinforced with 2Ø10 Steel on the perimeter of the opening", by 50%, 36.6%, 27.5%, and 23.2%, respectively.

The load capacity of the geopolymer concrete beam is enhanced by the use of "FRP bars and steel bars around the opening", according to the results.

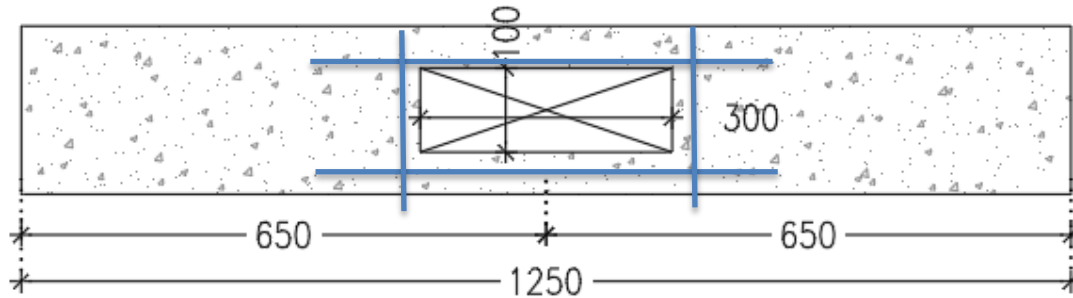


Fig. 15: The Proposed beams with opening.

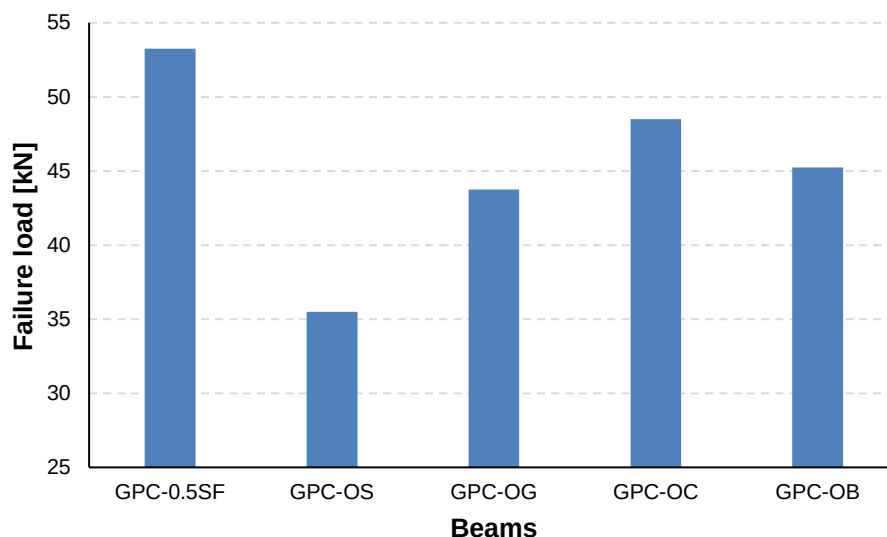


Fig. 16: Load capacity for beam GPC-0.5SF (without opening) and beams with opening.

6 Conclusion

After conducting a numerical study, the following conclusions were derived:

- 1) Numerical study by "ANSYS" software provides a detailed understanding of the structural behavior of GPC beams without stirrups after adding fibers to concrete.
- 2) The analytical results indicated an approximately 8.3% increase in the load capacity of specimens compared to the experimental results. Furthermore, there is a variation in the central deflection values of 8.7%.
- 3) Analytical results exhibited a reduction of 5.5% for the ductility factor values compared to those obtained experimentally.
- 4) The results show that using "steel fiber (SF)" improved the shear behavior of these beams due to the bond strength of SF and geopolymer mortar.
- 5) The analytical results show a lot of flexural shear cracks before failure in beams with steel fiber (SF).
- 6) The results show that using "carbon fibers (CF) in geopolymer concrete" increases the ductility factor of GPC beams.
- 7) The load capacity of the geopolymer concrete specimen increases with longitudinal reinforcement by the CFRP bar compared to those reinforcements by BFRP bars.

8) The load capacity of the geopolymer concrete specimen increases with the longitudinal reinforcements' increased diameter.

9) Having an opening in geopolymer concrete beams reduced the load capacity of these beams.

10) The load capacity of the geopolymer concrete beam is enhanced by the use of "FRP bars and steel bars around the opening", according to the analytical results.

Based on the findings of this investigation the following research points may be recommended for future work:

A. More experimental tests on geopolymer concrete beam with openings.

B. The effect of using geopolymer concrete in prestressed concrete.

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