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NUMERICAL ANALYSIS OF DOUBLE GEOPOLYMER CONCRETE LAYER WITH DIFFERENT PROPERTIES

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Abstract

Original scientific paper

Researchers have been working to find alternatives to conventionally produced concrete in recent years. Geopolymer concretes are also the focus of these studies. There are not enough studies on modelling geopolymer concretes, which are the subject of many experimental studies. In this study, the models of geopolymer concretes with different properties for two different loading and bearing conditions were solved by finite element method. In the analyses, the stress and strain conditions of the geopolymer concretes were analyzed by changing their locations. It was observed that when the geopolymer concrete with a lower modulus of elasticity and 100% slag content was on top, the stress values decreased, and the strain rates increased. The results obtained showed that the mechanical behavior of geopolymer concretes can be investigated much faster and easier with the finite element method as an alternative to experimental studies.

Keywords: *Geopolymer concrete, slag, finite element method, stress, strain.*

1 Introduction

Cement and the traditional concrete production process are polluting and leave much waste in the environment after use [1]. Geopolymer concretes, on the other hand, do not contain cement and, therefore, do not require the polluting cement production process. In addition, since waste products such as fly ash, blast furnace slag, silica, etc., are used in their construction, they help to dispose of these wastes. These concretes perform better than conventional concretes in terms of mechanical properties such as compressive strength, blast and impact strength [2] and are more reliable in terms of durability [3]. Geopolymer concretes are generally formed by initiating the hydration of a waste pozzolan or clay-derived matrix material with an activator such as sodium silicate or sodium hydroxide [4]. Although their Poisson ratios and densities are close, they may have different moduli of elasticity depending on their content [5]. Unlike conventional concrete, geopolymer concretes exhibit different behavioural characteristics under compressive and tensile stresses. Under compressive stress, while it initially exhibits linear elastic properties, its behaviour changes at a certain point.

Nguyen et al. [5] studied in detail the mechanical properties of heat-cured low-calcium fly ash geopolymer concrete and the behaviour of geopolymer concretes. They analysed the behaviour of the geopolymer layer using a bending test including four-point bending, elastic theory, and a finite element model. Their study observed that the measured tensile strength values of geopolymer concrete with fly ash admixture were higher than the calculated tensile strength values of Portland cement concrete.

Ganesan et al. [6] examined the strength and behavior of steel fiber-reinforced geopolymer concrete columns using experimental and analytical methods. The test results showed that the addition of steel fibers increased the axial strength and considerably modified the stress-strain behavior and elasticity of the columns. To better understand the stress-strain behavior of the column, a finite element model of the geopolymer column was developed using Ansys software.The results obtained from the finite element method analysis were observed to be satisfactorily similar to the experimental results.

Antonyamaladhas et al. [7] compared the mechanical properties of geopolymer concrete and conventional concrete elements with layer and L-section using experimental and finite element methods. Durability properties such as acid and sulfate resistance were performed for both geopolymer concrete and conventional concrete, and the results were compared. The results of acid and sulfate resistance tests showed that the strength of geopolymer concrete was higher.

Annapurna et al. [8] conducted experimental and analytical studies on finite element analysis using Ansys software to simulate the flexural behaviour of reinforced geopolymer concrete layers. The results of the analytical investigations were in close agreement with those obtained from the experimental studies. Thus, the developed finite element model was found to be a good option for predicting the flexural behaviour of reinforced geopolymer concrete layers.

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Abdul Aleem and Arumairaj [9] compared manufactured and natural sand-reinforced geopolymer-reinforced concrete layers with Portland cement-reinforced concrete layers using analytical and finite element methods. The natural sand-reinforced geopolymer concrete layer behaved like an ordinary Portland cement-reinforced concrete layer under flexural loads. It was observed that the manufactured sandy geopolymer reinforced concrete layer gave better results than reinforced concrete layers under flexural loads.

Waryosh and Ali [10] investigated the effects on the behaviour and strength of five supported composite-cased geopolymer concrete layers under full and partial interaction (70%) static loads. They concluded that when the same specimens differed in partial and full interaction, full interaction loading resulted in higher strength capacity and less deflection.

Yılmazer Polat et al. [11] researched the basic conditions for self-healing cracks in geopolymer mortars and geopolymer mortar preparation techniques. For this purpose, the effect of cure media on geopolymer mortars, the most appropriate methods of bacterial addition to mortar without encapsulation and the effect on the compressive strength of mortar were investigated. The results of the experiments determined that the samples with bacteria added to the mortar with appropriate methods contained fewer voids than those produced without bacteria.

Aydın [12] experimentally tested the impact strength effect of composite layers formed with geopolymer concrete, which is increasingly being used and traditionally known as Portland cement concrete. As a result of the study, it was concluded that composite specimens produced with geopolymer concrete were more resistant to impact.

Venkatachalam et al. [13] analysed the flexural behaviour of geopolymer concrete layers using the three-dimensional finite element method. They reported that the compressive strength of geopolymer concrete increases as the curing time increases and that the finite element method is a good alternative to the experimental method.

Yılmazer Polat ve Uysal [14] evaluated the healing of metakaolin-based geopolymer mortar cracks without any chemical healing. Yılmazer Polat [4] also investigated the healing of early microcracks in geopolymer mortars using a carbonate-precipitating bacterial agent and expanded perlite aggregate as a carrier. In the study, he observed that bacterial cells were able to sporulate directly on the expanded perlite aggregate. Therefore, the crack healing rate of the specimens was greatly improved, visually up to 100%.

Although there are many similar in-depth and diverse studies on geopolymer concretes in the literature, the behaviour of multi-layered geopolymer concrete elements under load has yet to be investigated in detail experimentally and numerically. This study's load-unit strain and displacement relationships of concrete under compression are numerically investigated.

2 Objectives

This paper uses the finite element method to analyze the displacement and deformation behaviour of 2 different geopolymer concrete blocks under 2 different support and loading conditions. In this way, it will be possible to compare the changes in the deformation and displacement behaviour of these geopolymer concretes with different moduli of elasticity under different types of supports and different loadings without performing experimental studies. This process, which is laborious and costly when done experimentally, is faster and less costly with the finite element method.

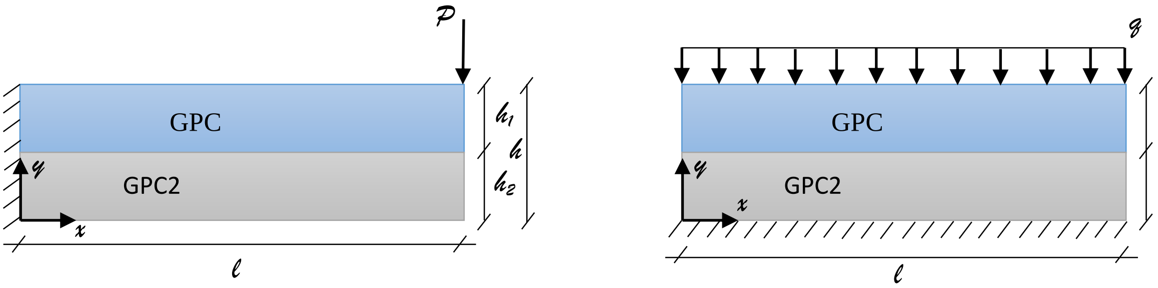
Geopolymer concretes are a new generation of concrete with high strength and superior physical and mechanical properties that do not require laborious and polluting cement production as they do not contain cement compared to traditional concretes. This concrete, which is also called green concrete due to its environmentally friendly properties, is a subject that has been intensively researched scientifically in recent years due to its advantages. The expected mechanical behaviour of concrete under loading is vital for achieving its intended use. Geopolymer concretes, like conventional concretes, may have many uses in the future, such as roads, barriers, dams, and foundations, and their stress and strain behaviours become important in these applications. In the literature, no study is investigating the shape and displacement behaviour of geopolymer concretes under different support and loading conditions by the finite element method. The aim of this research paper, which is a very original study in this respect, is to see the stress and displacement behaviour of two different content geopolymer concrete materials with different moduli of elasticity formed by pouring on each other.

3 Research Methodology

This study is based on the stress and strain analysis method of a system consisting of 2 different geopolymer concretes positioned on top of each other by considering 2 different support conditions and loading conditions using the ANSYS program. In the study, firstly, the geopolymer concretes under different loads were analyzed, and their behaviour in different axes were examined. Then, the geopolymer concretes were analyzed by changing their positions and the results were presented in tables and figures. The mechanical properties of geopolymer concrete 1 (GPC1) modelled in the study [7], and the mechanical properties of geopolymer concrete 2 (GPC2) [5] are the data taken from the studies in the literature. The material properties of the geopolymer concrete used in the functional stratified model are given in Table 1. Here, GPC1 concrete is composed of 60% fly ash and 40% slag and has a modulus of elasticity of 35000 MPa, while GPC2 with all fly ash matrix has a modulus of elasticity of 25000 MPa.

	Mixture		*Modulus of Elasticity (MPa)*	*Poisson Rate*
	Fly Ash	*Slag*		
GPC1	%60 (257.16 kg/m^3)	%40	35000	0.22
GPC2	%100 (387.10 kg/m^3)	-	25000	0.22

Geometric models for two different support conditions are given below.



(a) (b)

Figure 1. **a)** Cantilever layer model of geopolymer concretes. **b)** Loading of geopolymer layers resting on fixed support.

Figure 1a shows the loading conditions for fixed-supported geopolymer concrete. Figure 1b shows two different geopolymer concrete layers under uniformly distributed loading. In both cases, GPC1 and GPC2 were relocated and analyzed, and their deformation and displacement conditions were investigated.

The mechanical behaviour of two different geopolymer layers with different material properties under different loading and bearing conditions were investigated using the finite element method (FEM). The analyses were performed with the ANSYS Mechanical Launcher 16 program.

The Finite Element Method (FEM) is a numerical analysis method widely used in engineering and science. It is especially used to model and analyze the behaviour of complex structures. FEM is an approach in which numerical methods are applied to obtain the solution of a structure by transforming it into a system of differential equations. This method divides a geometric model into a finite set of elements or nodes and models the relationships between these elements with mathematical expressions. Each element could have properties such as material properties and geometric characteristics. The equations associated with these modeled elements represent the equilibrium condition and behaviour of the system. It uses mathematical methods and algorithms for numerical analysis. First, the geometry and material properties of the problem are defined. Then, the geometry of the problem needs to be divided into elements, and appropriate mathematical expressions need to be constructed for each element. These expressions could usually be in the form of differential or integral equations. Finally, these equations are combined as a system and solved by numerical methods to analyze the behaviour of the problem. The flowchart for the solution is given below:

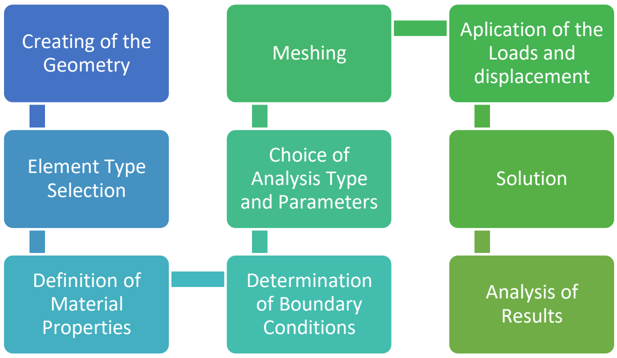
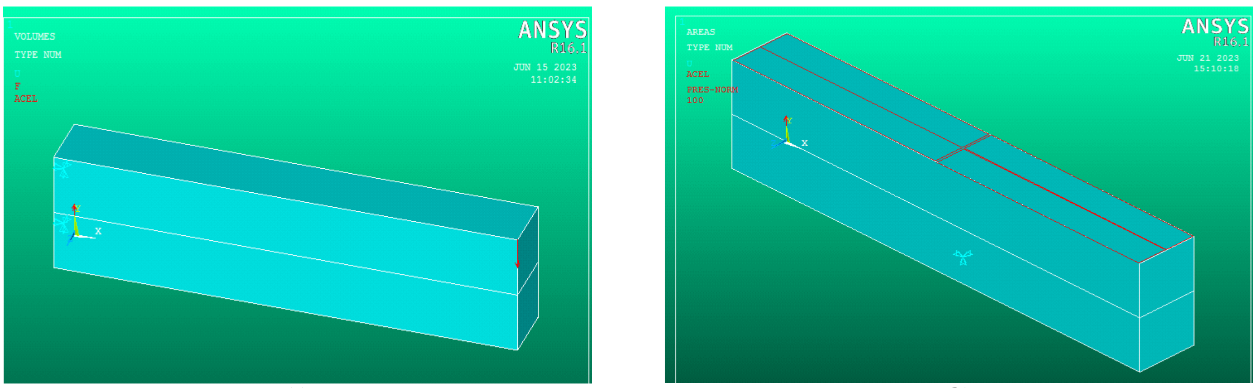


Figure 2. Flowchart of ANSYS solution.

4 Analytical Modeling Using Finite Element

Finite element models of the problem are given in Figure 3(a-b). In Figure 3(a), two geopolymer concretes were modeled, and a cantilever layer loaded a point on its end. In Figure 3(b), a model of geopolymer concrete loaded with uniformly distributed load from the top surface and resting on the fixed supports is given.



(a) (b)

Figure 3. a) Cantilever geopolymer concrete b) Resting on fixed support geopolymer concrete.

SOLID65 was chosen as the element type. SOLID65 is a type of finite element used in ANSYS software for structural analysis. SOLID65 is a four-node tetrahedric element and provides high accuracy and precision in three-dimensional analysis. This element calculates stress, deformation, temperature effects and other structural analysis parameters. Moreover, the material behaviour of the element is also suitable for plastic analysis using linear elastic or plastic deformation models. Figure 4 shows the operating principle of the element.

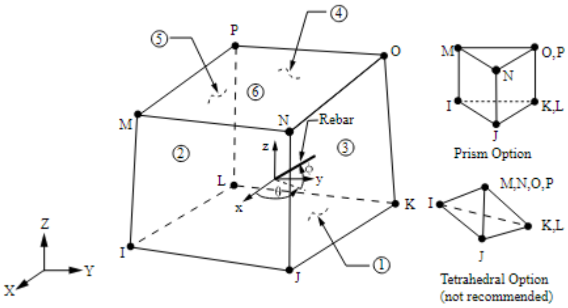


Figure 4. The operating principle of the SOLID65.

Once the material properties provided in Table 1 are introduced to the program and assigned to the geometries, a meshing process is carried out. The volumes have been divided into finite elements with 9333 nodes. A visual representation of the meshing process is provided in Figure 5.

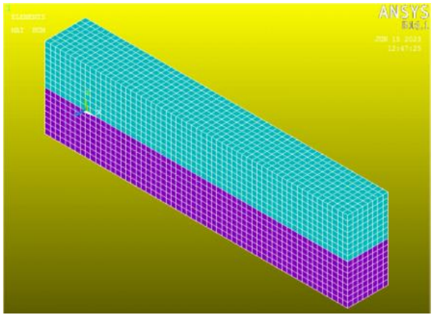


Figure 5. The geometric model is divided into meshes.

After defining the boundary conditions and loads in the problem to be analyzed statically, the solution phase started.

5 Results and Discussion

Figure 6 provides the displacement status of the console under loading conditions. Figure 7 illustrates the analysis of displacement values along the x, y, and z axes under varying P loads, with GPC1 positioned above and GPC2 below. The resultant findings are quantitatively detailed in Table 2.

In Table 2, the deformation behavior of geopolymer composite cantilever concrete loaded from the end has been numerically analyzed in the x, y, and z directions under different loads. In the first scenario, where the elasticity modulus is lower for the geopolymer concrete above and higher below, the deformation at the end of the layer was studied. In the x direction, it was observed that there was an elongation on the upper surface of the layer's endpoint and a contraction on the lower surface. It was determined that these elongation amounts increased when the positions of the geopolymer concretes were changed. The displacement in the y direction decreased when the concrete's positions were changed, while in the z direction, it increased. As the load increased, these elongation and contraction patterns also increased proportionally.

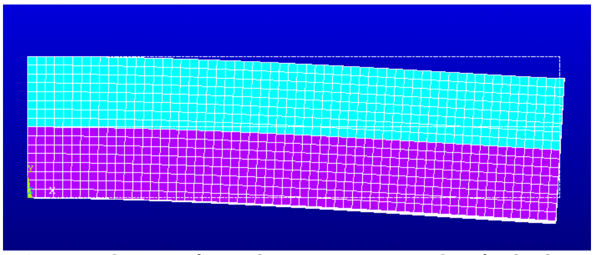
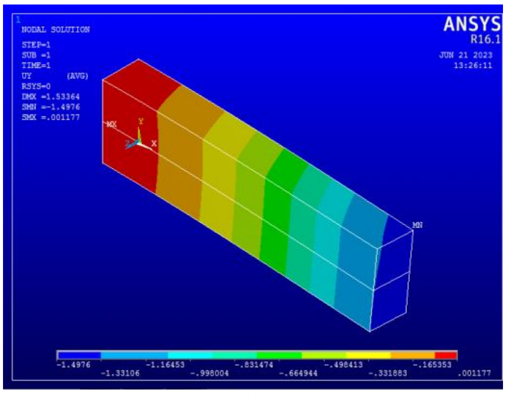
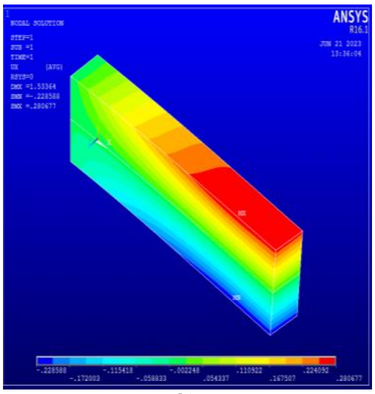


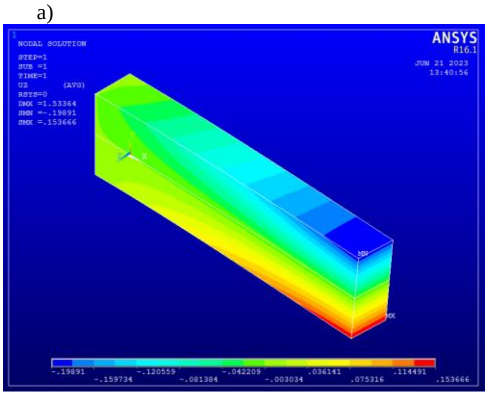
Figure 6. The state of geopolymer concrete consoles after loading.



a)



b)



c)

Figure 8. The alterations of geopolymer console concrete under loading between GPC1 and GPC2 δ_x, δ_y, δ_z (P=100, l=3).

Table 2. The shape deformation analysis of geopolymers concrete loaded from the cantilever's end is presented.

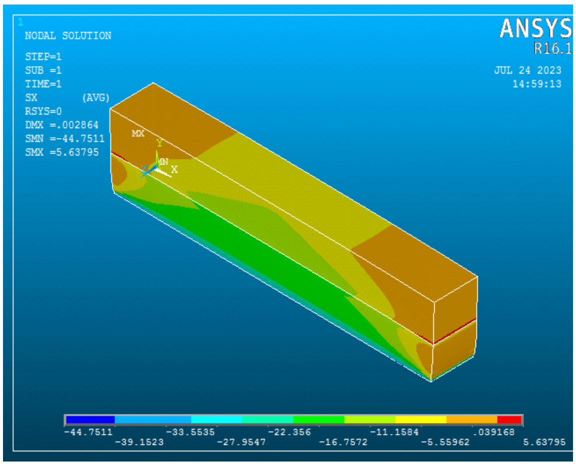
Load	*GPC1-GPC2*						*GPC2-GPC1*					
	y=0			*y=h*			*y=0*			*y=h*		
	δ_x	δ_y	δ_z	δ_x	δ_y	δ_z	δ_x	δ_y	δ_z	δ_x	δ_y	δ_z
P=100	-0.229	-1.50	0.15	0.28	-1.50	-0,20	-0,28	-1,48	0.20	0,23	-1,48	-0,17
P=200	-0,46	-2.99	0,31	0,56	-2,99	-0,39	-0,55	-2,97	0,40	0,45	-2,97	-0,34
P=300	-0,69	-4.49	0,46	0,84	-4,49	-0,60	-0,83	-4,47	0,60	0,67	-4,47	-0,51

In Table 2, the deformation behavior of geopolymer composite cantilever concrete loaded from the end has been numerically analyzed in the x, y, and z directions under different loads. In the first scenario, where the elasticity modulus is lower for the geopolymer concrete above and higher below, the deformation at the end of the layer was studied. In the x direction, it was observed that there was an elongation on the upper surface of the layer's endpoint and a contraction on the lower surface. It was determined that these elongation amounts increased when the positions of the geopolymer concretes were changed. The displacement in the y direction decreased when the concrete's positions were changed, while in the z direction, it increased. As the load increased, these elongation and contraction patterns also increased proportionally.

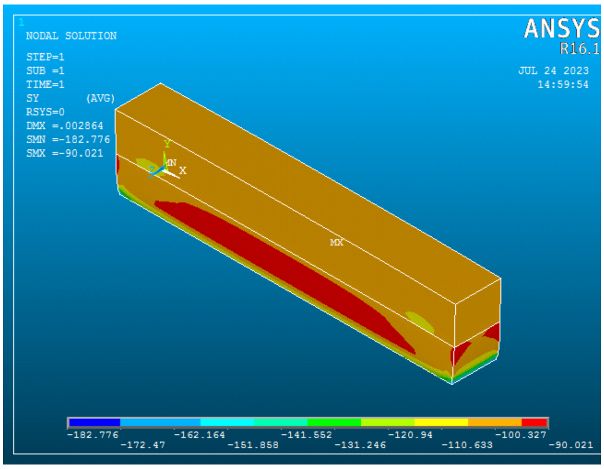
Table 3. Stress analysis of geopolymer cantilever concrete loaded with uniformly distributed load.

Yük	*GPC1-GPC2*						*GPC2-GPC1*					
	min			*max*			*min*			*max*		
	σ_x	σ_y	σ_z	σ_x	σ_y	σ_z	σ_x	σ_y	σ_z	σ_x	σ_y	σ_z
P=100	-48.72	-199.45	-51.11	6.09	-90.31	6.29	-44.75	-182.78	-46.81	5.68	-90.01	6.58
P=200	-97.43	-398.89	-102.22	12.18	-180.62	12.59	-89.50	-365.55	-93.62	11.28	-180.02	13.15
P=300	-146.15	-598.34	-153.33	18.27	-270.92	18.69	-134.25	-548.33	-134.25	16.91	-270.06	19.74

In Table 3, stress conditions of geopolymer composite concrete, which is fixed from below and loaded with a uniformly distributed load on its upper surface, under different loads have been examined. It was observed that when the concrete with a higher elasticity modulus is positioned at the top, stresses decreased in all directions. As the loads increased, proportional increases in stresses were observed. The stress conditions of geopolymer cantilever concrete layers under different loadings after analysis are presented in Figure 8.



a)



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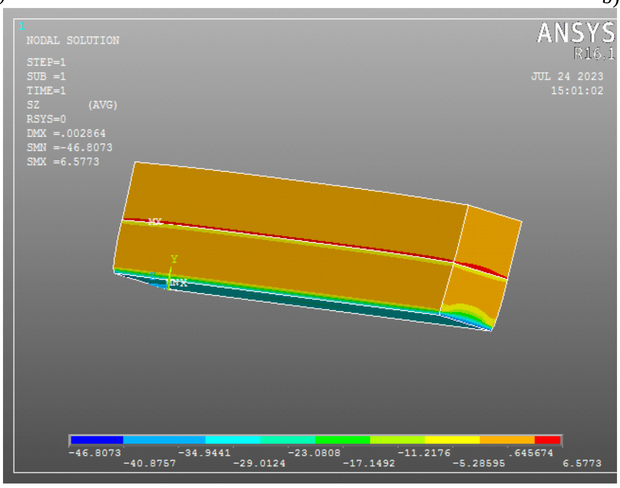

c)

Figure 8. The stress conditions in different directions of GPC2-GPC1 (q=200, *l*=3, σ_x, σ_y, σ_z).

6 Conclusions

In this study, stress and deformation analyses were conducted on two geopolymer concrete layers with different material properties under different support and loading conditions. The layers were named GPC1 and GPC2 based on their properties. The analyses were performed by comparing the results with changes in the positions of the geopolymer layers. When GPC1, with a higher elasticity modulus, was positioned at the top, the deformation amounts were greater than those of GPC2. On the other hand, when GPC1, with a higher elasticity modulus, was positioned at the top, stress values were lower than in the other scenario. Most of the studies in the literature on geopolymer concrete consist of experimental studies. The main objective of this study is to investigate the mechanical behavior of geopolymer concretes using the finite element method, which is an alternative solution method. The results obtained showed that the mechanical behavior of geopolymer concretes can be investigated much faster and easier with the finite element method as an alternative to experimental studies.

Declaration

Ethics committee approval is not required.

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