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NUMERICAL SIMULATION OF NONLINEAR BEHAVIOUR AND FAILURE PATTERNS OF GEOPOLYMER CONCRETE BEAMS

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Abstract

Finite Element Analysis (FEA) was performed using ANSYS Workbench to simulate the structural response of GPC beams under two-point loading and to validate the experimental results. A three-dimensional nonlinear finite element model was developed considering material nonlinearity, cracking in tension, and crushing in compression using SOLID65 and LINK8 elements. Parameters such as load–deflection behaviour, stress distribution, crack patterns, first cracking load, ultimate load, and failure modes were analyzed. The Newton–Raphson iterative method was employed to achieve convergence in nonlinear analysis. The analytical results were compared with experimental findings for different geopolymer mixes and molarity levels.The results indicate a good correlation between experimental and numerical outcomes in terms of load-carrying capacity, deflection, and failure patterns. Finite element models were found to be slightly stiffer than experimental beams due to the assumption of perfect bond between concrete and steel reinforcement and the absence of microcrack effects in the numerical model.. Higher alkaline molarity and fibre content improved stress distribution and load resistance.

1. Introduction

The Finite element method is an extremely useful tool of analysis in many fields of Engineering. Finite Element Analysis is an accurate and flexible technique to forecast the performance of a structure, mechanism or process under different loading conditions. The structural behaviour observed during the tests was used for develop a FEM, particularly during the non linear analysis. In angles under tension, the behaviour is highly nonlinear as the failure approaches. Static analysis is conducted as Finite Element Analysis (FEA) using ANSYS Workbench. To simulate the flexural behavior of geopolymer concrete beams tested experimentally. To evaluate deflection, crack formation, and stress distribution using finite element analysis.

2. Finite Element Analysis

Finite element analysis as applied in engineering is a computer tool for engineering and 3D structural solid elements analysis. It is a way of stimulating load conditions in a design and determining the response of the design to these conditions. The design is modeled using discrete building blocks is called elements. The FEM method is a numerical method for finding approximate solutions to limit value problems for partial differential equations. It is also known as an analysis of Finite Elements (FE). FEM divides a large problem into smaller, simpler called finite elements. CivilFEM is a set of ANSYS integrated pre- processing, solution and post- processing application which makes it easier for the user to deal with civil engineering issues. The aim of the Finite Element Analysis is to develop a model that can study the behavior of single and double angle bolted cold formed steel components. The behaviour observed during the tests was used for preparing a finite element model, particularly during the nonlinear analysis. In angles under tension, the behaviour is highly nonlinear as the failure approaches. The model of finite elements included both geometric and nonlinear material effects. The front edge of the guesset plate is restricted in all directions except the longitudinal direction. On the front edge of the gusset plate, a longitudinal displacement limit condition is applied. The maximum stress and strain are obtained around the bolt hole. structures and materials under various loads and conditions. FEA divides a complex structure into smaller, simpler parts called "elements" connected at nodes. The solutions for individual elements are then assembled to create a global solution for the entire domain.

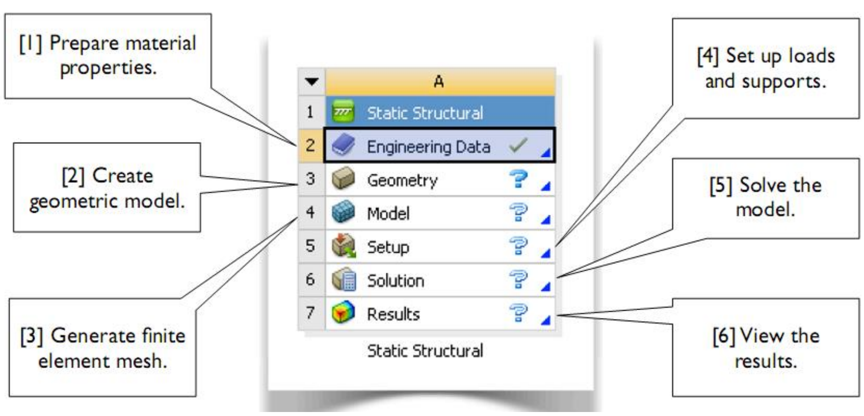

Fig 1 Static Structural Simulations

3. Literature Review

Hardjito et al. (2005) The manufacture of fly ash-based geo polymer concrete proceeded with the combination of NaOH and Na2SiO3 was chosen to activate the fly ash resulted in the higher compressive strength during the increase in the sodium hydroxide/ sodium silicate ratio. The similar kinds of research were regulated and formulated the design procedure for the various combinations of alkaline activators according to This makes it a more sustainable and environmentally friendly alternative to traditional concrete, with the potential for reduced carbon emissions and the use of industrial waste products.

Jayesh kumar, Pitroda and Umrigar (2013) based on limited experimental investigation concerning the water absorption and sorptivity of concrete, the following observations are made regarding the resistance of partially replaced fly ash for M25 and M40 grade concrete: The water absorption and sorptivity of fly ash concrete shows lower water absorption and sorptivity at 10% replacement with fly ash for M25 and M40 grade concrete. Thereafter the water absorption and sorptivity show an increasing trend. For 90 days strength, where percentage decrease in water absorption is found to be 1.59% for M25 and 0.67 for M40 and sorptivity is found to be 2.32 mm/min0.5 for M25 and 1.74 mm/min0.5 for M40 with respect to reference mix

Jay G Sanjayan, Ali Nazari and Hesam Pouraliakbar (2015) conducted Finite Element Analysis modeling of fracture toughness of steel fibre-reinforced Geoploymer composites was done by Nine types of Geoploymer paste were prepared with different ratios of sodium hydroxide to sodium silicate weight, alkali activators to fly ash weight, sodium hydroxide concentration and curing temperatures. The fracture toughness of members was calculated from pre-notched three-point bending tests. The Geoploymer pastes were reinforced with steel fibres with a volume percentage of 2, 3 and 5% in the mix with the fibre length and diameter of 30 mm and 0.5 mm respectively. The test results revealed that there was no considerable variation between predicted and experimental results because of alkali activator to fly ash weight and sodium hydroxide to sodium silicate ratios. On the other hand, there was a drastic change between predicted and experimental results due to the curing temperature and sodium hydroxide concentrations. The analytical model results indicated that the percentage increase in the volume of steel fibres produced optimum effects on the point of fracture toughness. It was concluded that the proposed FEA modeling could be applied for predicting the fracture toughness.

Jonathan Tailby and Kenneth JD MacKenzie (2010) investigated the mechanical properties and structure of alumino-silicate Geoploymer concrete prepared with ordinary Portland cement. X-ray diffraction, 29Si and 27Al MASNMR, and SEM/EDS methods were employed to study the strength and microstructure of the Geoploymer concrete. Geopolymer concrete is economical, low energy consumption, thermally stable, easily workable, eco-friendly, cementless, and durable It was found that in the development of Geoploymer concrete, the hydration of OPC and other cementitious compounds was delayed despite the presence of water in adequate quantity. From the SEM studies, it was discerned that because of the formation of an impervious layer around the cement particles, the strength development was delayed.

4. Finite Element Model

A finite element model of the beam was being modeled and the loading procedure has been carried out using the finite element software ANSYS. ANSYS is a comprehensive FEA analysis (finite element) tool for structural analysis including linear, nonlinear and dynamic studies. The engineering simulation product provides a complete set of elements behavior, material models and equation solvers for a wide range of mechanical design problems. The finite element model was developed to simulate the flexural behavior of reinforced geopolymer concrete (GPC) beams under two-point loading conditions. The modeling was done using ANSYS Workbench to analyze stresses, crack formation, and deformation characteristics, and to compare them with OPC beams under similar conditions. The steps involved in the FEA are as follows : Figure 5.2 shows finite element model.

- Element types, Real constants , Material properties , Modeling , Meshing
- Boundary conditions and loading and Analysis and results

4.1 ANSYS Model Parameters

- Mesh Size: 10 mm
- Boundary Conditions: Fixed at one end, uniformly distributed load at the other.
- Material Properties:
- Elastic Modulus: 28 GPa (M3 mix)
- Poisson's Ratio: 0.25
- Density: 2400 kg/m³;
- Load Applied: 50 kN
- Analysis Type: Static Linear Analysis

Software: ANSYS Workbench 2023

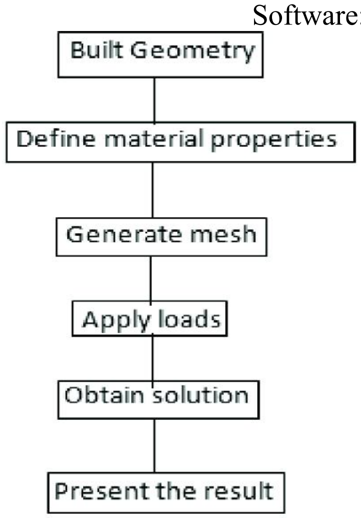

Fig 2 Finite Element Model

4.2 Element Types

ANSYS literally provides hundreds of element types. To identify these element types, each element. By default the workbench automatically chooses appropriate element types from an element library according to the type of structural bodies involved in the project. Geometry, loading and required results must all be evaluated in the selection process of the elements. The program has a wide library of element types. Some of the features and groupings of the element types are described in this chapter to make it easier to select the element type.

FEMGEN will generate a finite element mesh of nodes and geometric element types. These geometric element types are related to the ANSYS element names via an element variant number. Element variants are assigned using the command Meshing Types part El type variant no. The element type number is assigned by the interface program. The same element type can be defined twice with two different numbers if its material or and physical properties are different from one to the other. The element type number is used in the ANSYS 'TYPE' command issued with the element's definition. In the Ansys program, plane42 is a 4 node isoperimetric element with 2 degrees of freedom at each node.

SOLID 65 is used for the 3-D modeling of solids with or without reinforcing bars(rebar). The solid is capable of cracking intension and crushing in compression. The element is defined by eight nodes having three degrees of freedom a teach node translations in the nodal x,y,and z directions' three different rebar specifications may be defined. Table 5.1 shows the element type which were utilized to construct the finite element model of the beam.

Table 1 Element types used in the beams

Materials	Element type
Fibre Reinforced Concrete	Solid 65
Stirrups	Link 8
Top reinforcement	Link 8
Bottom reinforcement	Link 8
Steel Plates	Solid 45

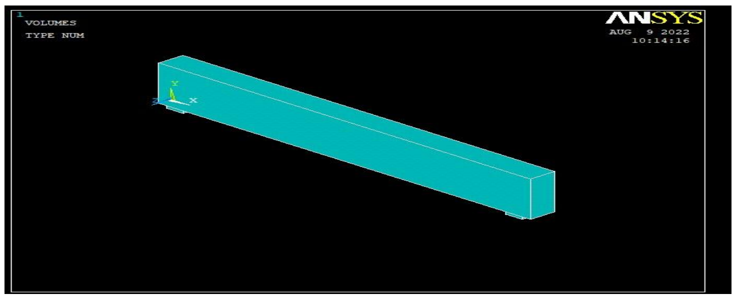

Fig 3 Beam Modelling

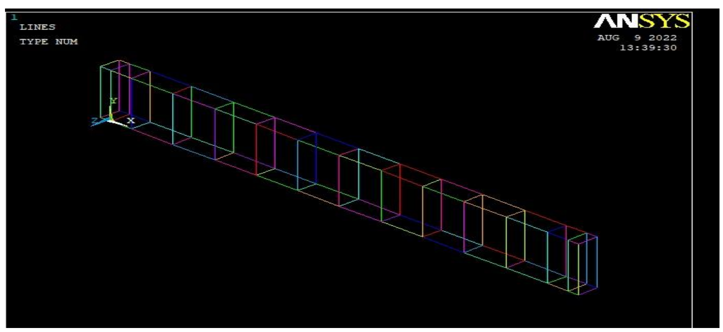

Fig 4 Connects Beam Modelling

5. RESULTS AND DISCUSSION

5.1 Nonlinear Analysis

To obtain a nonlinear solution in ANSYS, the load applied to the model was distinguished into a series of load increments called load steps. After the analysis of each incremental solution, the adjustment in the stiffness matrix of the model was carried out to replicate the nonlinear changes in the structural stiffness before proceeding to the subsequent load increment. To realize nonlinear solutions to the model, the model stiffness was updated by Newton–Raphson equilibrium iterations. By using the checks and out-of-balance loads for convergence, a linear solution was obtained. If the convergence condition was not satisfied, the out-of-balance load vector was reassessed, the stiffness matrix was modified, and a new solution arrived. In order to get the convergence of the solutions, the convergence tolerance limits were taken as 0.1 for both force and displacement.

5.2 Failure Pattern

The failure pattern of geopolymer concrete (GPC) beams, especially when tested under flexural loading (such as two-point bending), is a crucial indicator of the material's ductility, crack resistance, and load-bearing behavior. When a maximum load of 20 kN was applied on GPC beam, it could not carry additional loads as signified by a significant convergence failure. A rigorous crack was developed throughout the whole constant moment region, and more cracks have propagated to the top of the beam. It was also observed that before the failure of the beam, some of the compressive cracks appeared at the top part of the beam because of crushing failure of the concrete as denoted by the red lines in ANSYS chart

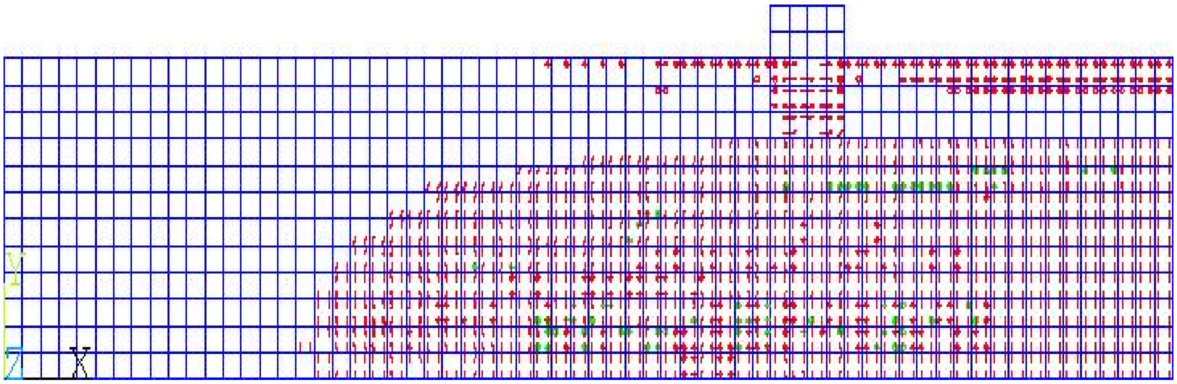

Fig.5 Failure of GPC beam with 10M for M40 – Mix 2

Table 2 Comparison of Ultimate Load in GPC beam for M40

BeamID	**Ultimate Load(kN)**		**Experimental (Ec)/ Ansys (Ac)**
	Experimental (Eu)	Ansys (Au)	
Mix-1	65.87	87.34	1.33
Mix-2	77.35	87.22	1.13
Mix-3	79.75	91.45	1.15
Mix-4	85.43	92.43	1.08
Mean			1.11
Standard Deviation			0.13

Table 3 Comparison of Ultimate Moment in GPC beam for M40

BeamID	**UltimateMoment (kNm)**		**Experimental (Ec)/ Ansys (Ac)**
	Experimental (Em)	Ansys (Am)	
Mix-1	9.27	16.32	1.76
Mix-2	10.92	11.31	1.04
Mix-3	12.89	13.11	1.02
Mix-4	15.76	16.48	1.05
Mean			1.14
Standard Deviation			0.15

Table 4 Comparison of Deflection in GPC beam for M40

BeamID	Deflection (mm)		Experimental (Ec)/ Ansys (Ac)
	Experimental (Ed)	Experimental (Ec)/ Ansys (Ac)	
Mix-1	44.2	65.32	1.48
Mix-2	34.3	35.31	1.03
Mix-3	30.4	31.11	1.02
Mix-4	27.8	29.48	1.06
Mean			1.16
Standard Deviation			0.18

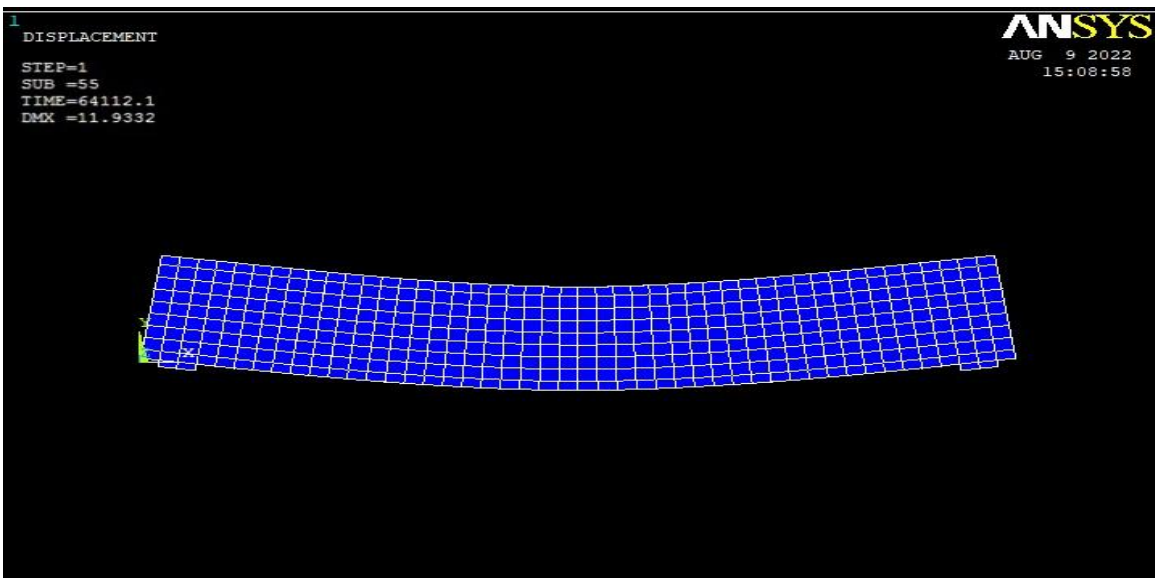

Fig.7.5 Beam meshing in Mix 4 for M40

6.Conclusion

This study investigated the flexural behaviour of geopolymer concrete (GPC) beams with and without steel fibre reinforcement through experimental testing and nonlinear finite element analysis using ANSYS Workbench. The analytical results showed good agreement with the experimental findings in terms of load–deflection behaviour, stress distribution, crack patterns, and failure modes, confirming the reliability of the developed finite element model.

The finite element model was found to be slightly stiffer than the experimental beams due to assumptions of perfect bond between concrete and steel reinforcement and the exclusion of microcrack effects in numerical simulation. Despite this, the overall correlation between experimental and numerical results was satisfactory, demonstrating that FEA can effectively predict the structural response of geopolymer concrete beams.

The inclusion of 1.0% steel fibres significantly improved the load-carrying capacity, ductility, and post cracking performance of geopolymer concrete beams. Higher alkaline molarity also enhanced the mechanical properties and flexural strength of GPC beams. Stress distribution patterns confirmed that fibre-reinforced geopolymer concrete exhibited better crack control and more uniform load transfer compared to conventional mixes.Based on the results, geopolymer concrete, especially when reinforced with steel fibres, can be considered a promising and sustainable alternative to ordinary Portland cement concrete for structural applications. Finite element modeling using ANSYS provides an efficient and economical approach for predicting the behaviour of geopolymer concrete beams, reducing the need for extensive experimental testing.

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