Numerical Analysis of Alkali Activated Geopolymer Concrete Slab under Impact Load

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ABSTRACT

Researchers focuses on their study on sustainable and environmentally friendly building materials like Geopolymer concrete (GPC). There were several studies done in the literature to find the performance of GPC structural members under different loading conditions and checked their performance against Ordinary Portland cement (OPC) concrete. Slabs are the most important structural members and it is very significant to find the behaviour under impact loads and it is not always adequately understood. The purpose of this study is to examine how an alkali-activated slag slab behaves under impact loading and utilizing the ANSYS software, a 3D nonlinear finite element analysis was performed. To validate the numerical model that was utilised, the slab models were first calibrated using existing experimental data and then parametric tests were conducted utilising various reinforcement ratios and their spacings. The results showed that GPC slabs showed better performance and the deformation decreased with increase in reinforcement ratios.

Keywords: Alkali activated geopolymer concrete, Numerical analysis, Impact loading.

1 Introduction

Geopolymer concrete (GPC) is an emerging sustainable replacement for Ordinary Portland cement (OPC) concrete and numerous studies were conducted on GPC structural members. The production of OPC uses a lot of natural resources and has a significant impact on greenhouse gas emissions; for every 1kg of OPC production releases 0.66 to 0.82 kg of CO_2 to the atmosphere. The GPC includes solid binder precursors like slag and fly ash- which are new cementitious material obtained by industrial byproducts, reduces CO_2 emissions by 75 to 84%, compared to the production of conventional concrete [1], [2]. An inorganic aluminosilicate polymer called geopolymer is developed by alkalinizing industrial waste materials that are high in Al_2O_3 and SiO_2. Combinations of sodium hydroxide (NaOH) and water glass (Na_2SiO_3) solutions are the most common alkali activator utilized. In comparison to conventional concrete, the GPC offers improved mechanical characteristics, stronger fire resistance, low creep, low shrinkage, and better durability against salt and acid attack. [3]–[5]. Studies conducted in the past on GPC beams and columns revealed that their failure mode and load-carrying capacity were comparable to those of conventional concrete elements[6], [7].

Slabs are structural members which are not generally designed for loads which are unpredictable like impact loads and seismic loads. Impact load is a high-magnitude force having a short duration of action and a random time of occurrence and the behaviour of structural members under such a dynamic load is completely different compared to the usual static loading condition. In finite element analysis (FEA), as finer element size was used for the meshing Reinforced GPC beam under impact load software was able to predict the experimental ultimate load by 99.46% and theoretical ultimate load by 96.11 % [8]. The experimental study includes the behaviour of reinforced concrete (RC) slabs under impact load, with a drop mass of 50 kg and drop height of 1.5 m by varying the longitudinal reinforcement [9]. The results showed that RC slabs at a slow rate of loading showed failure in a ductile manner (flexural failure) and punching

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failure in a brittle manner (shear failure). The use of steel reinforcement in concrete induced both localized punching shear failure and brittle failure [10]. The increase in slab longitudinal reinforcement ratio did not affect its impact responses.

The presence of the opening in RC slabs caused negative effects on the slab's performance and it has been found that the ultimate and residual displacement values increased by 80% to 88% with an increase in the opening size [11]. Strengthening with carbon fibre reinforced polymer (CFRP) enhanced the toughness and stiffness characteristics and ultimate displacement values decreased. The remaining displacements of the RC slabs were greatly decreased by CFRP strengthening as well. Previous research used ABAQUS software to analyse the finite element models of RC slabs reinforced with CFRP strips [12]. They proposed that improving the impact resistance of RC slabs by adding a thin coating of strain hardening cementitious composites to either tension side. Despite the advantages of GPC over OPC, there is very little experimental or numerical study conducted on alkali-activated geopolymer members like slab. Alkali activated geopolymer concrete slab under impact loading behaviour with changing reinforcing ratio has not been studied.

2 Materials and Methods

The method of action chosen for the finite element analysis of alkali activated GPC slab based on the background details and data gathered from a literature is shown in Figure 1.

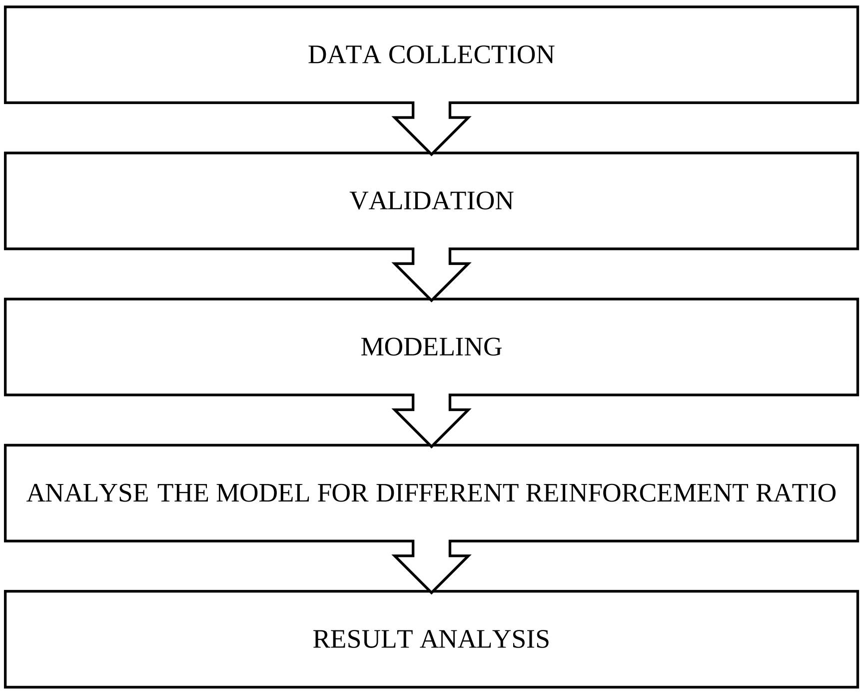

Figure 1: *Schematic representation of methodology*

For modelling, the engineering data regarding the alkali activated geopolymer concrete such as density (2400 kg/m^3), compressive strength (30 MPa) poisson's ratio (0.18) is taken from Zerfu and Ekaputri [8]. Four slabs were modelled in total, of which one is with OPC for validating the study and the rest are GPC slabs. The dimensions of the modelled slab are shown in Figure 2 and the impactor are represented in Figure 3. The impact loading details regarding mass of impactor as 50 kg and height of fall as 1.5 m are taken from Said and Mabrook [9]. The slab reinforcement details are shown in Figure 4 and the different reinforcement ratio for each slab model is provided in Table 1.

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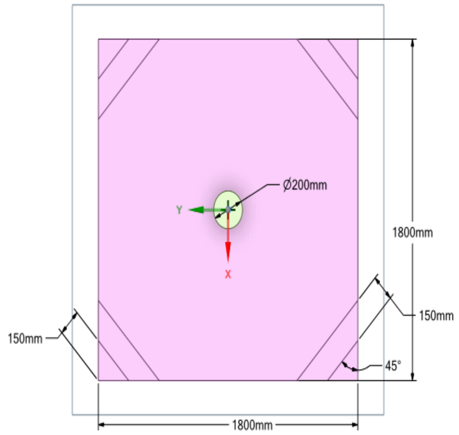

Figure 2: *Geometry of slab*

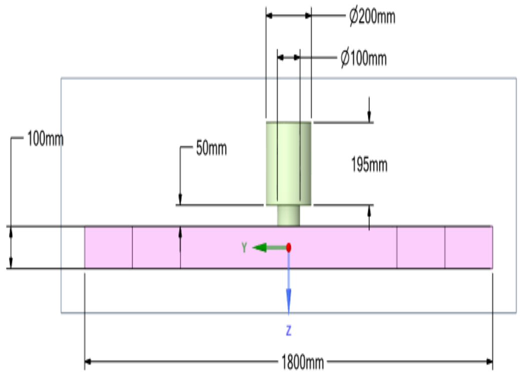

Figure 3: *Dimensions of impactor*

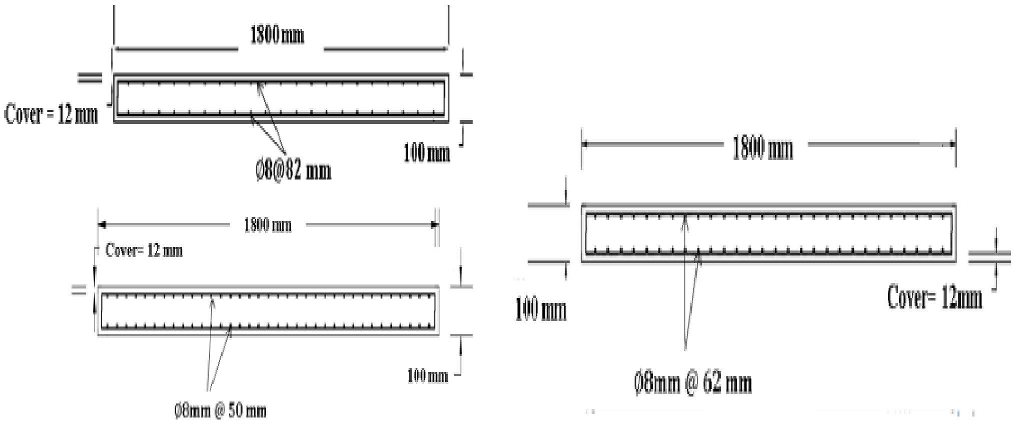

Figure 4: *Slab reinforcement Details* [9]

Table 1: *Simulation Details*

Model	Dimension (mm)	Reinforcement ratio (%)
C0	1800 X 1800 X 100	0.58
G1	1800 X 1800 X 100	0.58
G2	1800 X 1800 X 100	0.80
G3	1800 X 1800 X 100	1.00

3 Validation of Software

The Software was validated as per experimental study directed in Elnagar et al. [10] on the impact resistance characteristics of RC slabs. The numerical 3D model of the slab was simulated by using ANSYS software. To ensure required calibration the material data of concrete and steel was inputted and a proper meshing with a mesh size of 50mm. Figure 5 shows the meshing in the validated model. The boundary conditions were applied by applying fixity at the corners and impact loading was applied as per the experimental data retrieved from the literature. Then the results of the numerical study were related with the experimental results, it was found that FEA results were within the acceptable limits and hence, software was considered as validated.

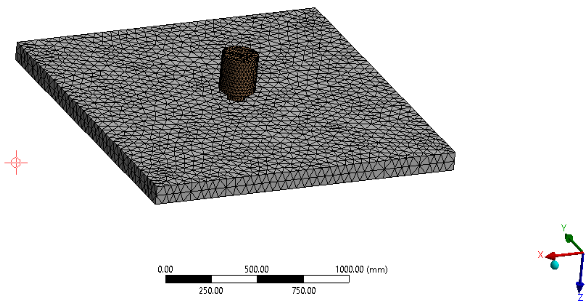

Figure 5: *Meshed model of RC Slab*

4 Results and Discussion

The analysis of FE models of GPC slabs under impact load could primarily yield the impact force- time history and deformation- time history. The results obtained through this study and their subsequent inferences are discussed below. The behaviour of GPC slabs under impact load is represented in Figure 6 and the effect of increase in reinforcement ratio on the slab behaviour was numerically analysed using the ANSYS software.

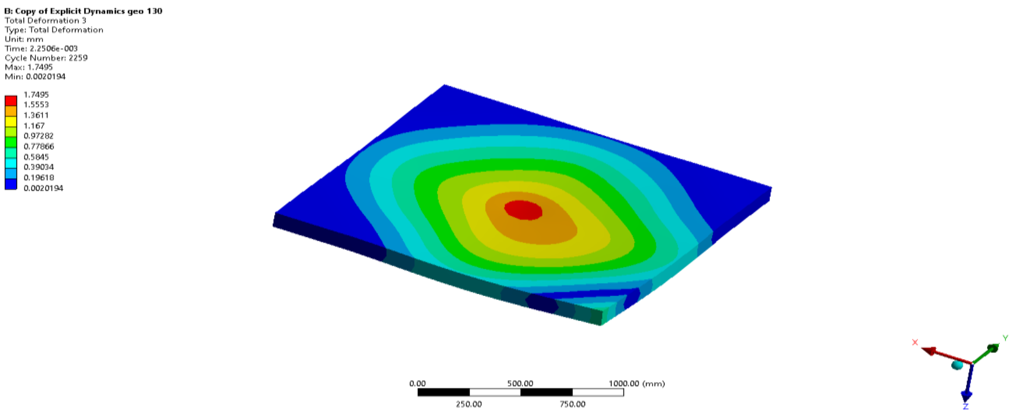

Figure 6: *Meshed model of RC Slab*

4.1 Impact force-time history

The impact load versus time graph for OPC and GPC slabs are demonstrated in Figure 7 and Figure 8 respectively. From Figure 7, it is clear that that the peak impact force is significantly increased in the case of GPC slabs when compared to OPC slabs. Due to the ability to disperse kinetic energy produced by the striking velocity in slab C0, the damage and deflection are amplified. Due to the increased deflection and damage the peak impact force is reduced. In case of GPC slab this deflection and damage is reduced which results in higher impact force. The peak impact force of GPC slab is 39.6% more than OPC. The Figure 8 shows that the peak impact force of GPC slab increases with reinforcement ratio. Increase in reinforcement reduces the deflection and damage which in turn increases the peak impact force. There is a rise in peak impact force by 46.5% and 102% for a reinforcement ratio of 0.8 and 1.0% when compared to 0.58%. The peak impact force values are shown in Table 2.

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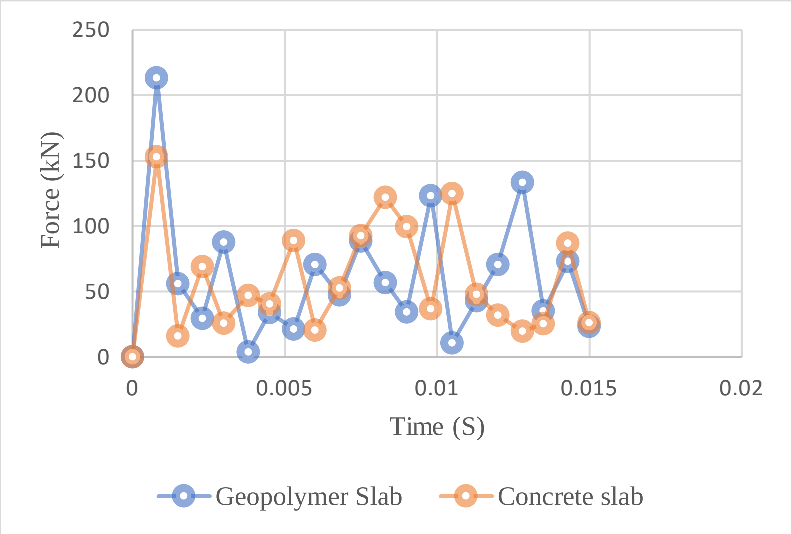

Figure 7: *Impact force-time history of GPC and OPC slab*

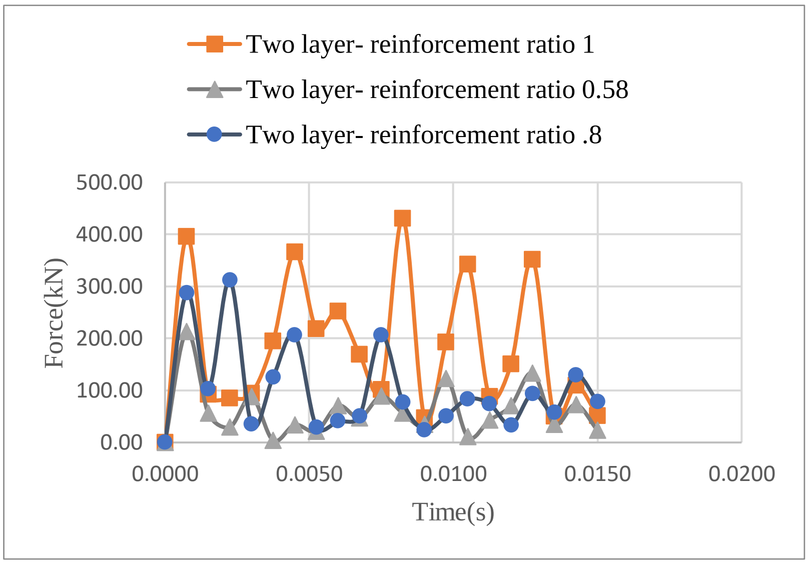

Figure 8: *Impact force-time history of GPC slabs with different reinforcement ratio*

4.2 Displacement-time history

The midpoint displacement time history of slabs is shown in Figure 9 and Figure 10 respectively. From the graph it can be understood that the maximum displacement of GPC slab is less than OPC slab. That is maximum displacement is reduced from 3.02 to 1.68 mm, that is about 44% reduction in midpoint displacement. The increase in steel reinforcement does not have a considerable effect on reducing maximum displacement. The midpoint displacement of GPC slab with reinforcement ratio of 0.58%, 0.8% and 1% are 1.68,1.66 and 1.61mm respectively. The reduction in displacement is not even more than 5%. The peak displacement in slabs is summarized in Table 2.

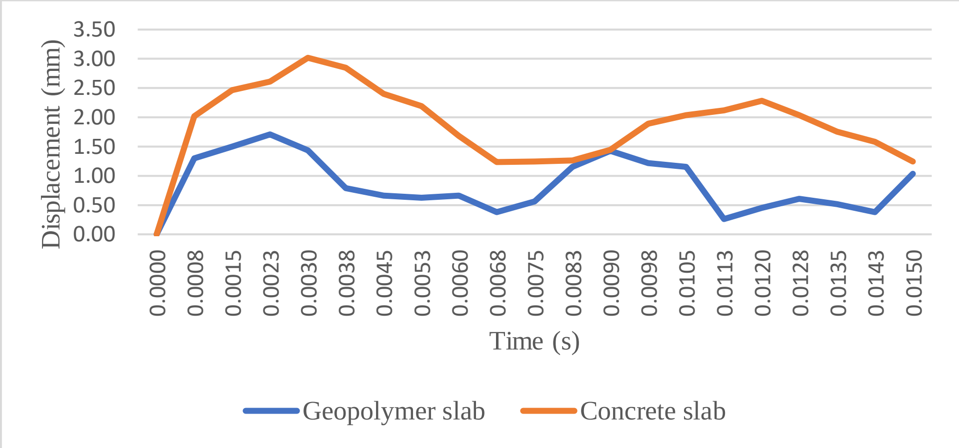

Figure 9: *Displacement-time history of GPC and OPC slab*

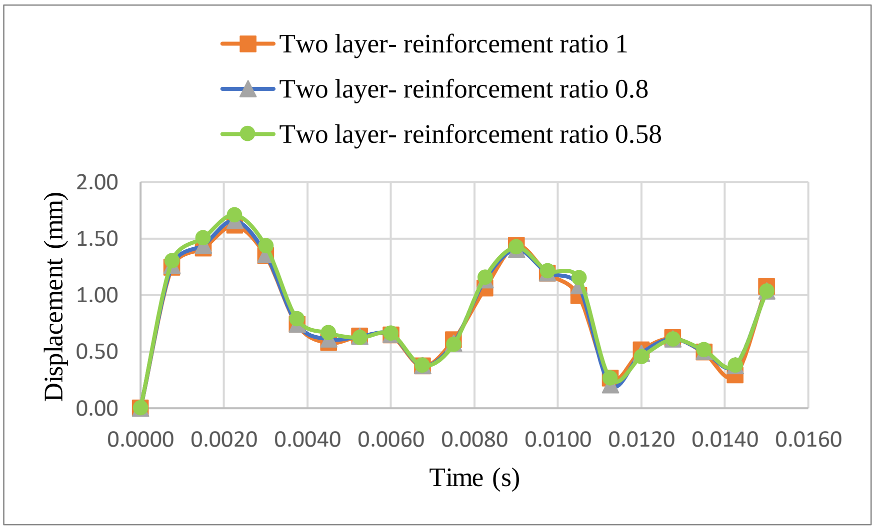

Figure 10: *Displacement-time history of GPC slabs with different reinforcement ratio*

Table 2: *Stimulation Results*

Model	Reinforcement ratio (%)	Maximum Displacement (mm)	Peak Impact Force (kN)
C0	0.58	3.02	152.89
G1	0.58	1.68	213.07
G2	0.80	1.66	312.21
G3	1.0	1.61	430.98

5 Conclusions

The numerical analysis done on ANSYS software showed the behaviour of alkali activated geopolymer concrete (AAGPC) slab under repeated impact load. From the numerical analysis done on geopolymer concrete (GPC) slabs with change in reinforcement ratio, we can arrive at the following conclusions-

- The use of AAGPC is efficient for the building purposes in construction industries.
- The performance of GPC is superior to conventional concrete. That is about a 39.4% increase in peak load and 44% decrease in maximum displacement.

- The reinforcement ratio can be reduced for geopolymer slabs to deliver the same performance as that of conventional concrete slab
- The steel reinforcements enhanced the strength and performance of GPC.
- The impact load resisting capacity of the slab increases with higher reinforcement ratio. The peak impact force increased by 46.5% and 102% for slabs with a reinforcement ratio of 0.8 and 1.0%.
- There is no considerable reduction in peak displacement with increase in reinforcement.

6 Publisher's Note

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How to Cite

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