International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 7 **Issue:** VI **Month of publication:** June 2019

DOI: http://doi.org/10.22214/ijraset.2019.6053

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.177
Volume 7 Issue VI, June 2019- Available at www.ijraset.com

A Study on Flexural Behaviour of Rectangular GPC Slabs having Partially Restrained Supports using ANSYS Software

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Abstract: In civil engineering practice reinforced concrete (RC) slabs are considered as an important structural element in enclosing a space with other elements. There were different methods introduced to calculate the ultimate loads that can be carried by a RC slab. Among these ultimate load methods, yield line theory has been widely adopted. Johensen's yield line theory is used to determine the flexural capacity of a RC slab i.e. capacity of slab excluding membrane forces in the slab. Geopolymer concrete is one of the emerging construction materials as a substitute for conventional cement concrete as it eliminates the usage of ordinary Portland cement (OPC). It is said that production of one tonne of cement emits approximately one tonne of carbon dioxide (co₂) into atmosphere. In order to minimize the liberation of CO_2 to air, alternative materials have to be used to replace the cement. Geopolymer concrete is one such material which replaces cement completely by waste materials such as GGBS, fly ash etc. which is also harmful to the atmosphere. This work is aimed to create analytical models of rectangular high strength traditionally vibrated concrete (HSTVC) and high strength geopolymer concrete (HSGPC) slabs with partially restrained support conditions and to carryout analysis in ANSYS software, the obtained results are then compared with that of experimental values. Totally eight slabs of dimensions 1500mm x 1000mm x 65mm are analysed by applying simulated uniformly distributed load. The slabs were divided into two categories, with each category containing four slabs each. First category contained HSTVC and the second category contained HSGPC of grade M60. Here ANSYS V 16.2 software was used to prepare and analyse non-linear finite element models of the test specimens. Load deflection behaviour, ultimate load enhancement beyond Johansen's load were obtained and compared with that of experimentally obtained values. ANSYS results demonstrate a sensible concurrence with the test yield. From the considered analysis it can be concluded that the ultimate load carrying capacity obtained in ANSYS is more than the experiment.
Keywords: HSTVC, HSGPC, ANSYS, FEM analysis, load deflection behaviour, load enhancement, percentage of reinforcement

I. INTRODUCTION

RC slab is a horizontal structural element made of steel reinforced concrete which nearly consumes forty percent of concrete used for the whole building. The slab is required to carry the applied loads such as dead load, superimposed load, floor finishes etc. which acts directly on the slab. The loads which are acting on the slabs are then transferred to the surrounding supports. Usually the behaviour of slabs is mainly governed by the edge support conditions and slab length along both shorter and longer directions.

In present day, construction practice is more dependent on concrete, where OPC is the main constituent. There is a change in the climate due to global warming, which occurs mainly due to the emission of greenhouse gases. Cement production itself contributes approximately 7% of CO_2 globally. In construction field cement is the highly demanded material. But the production of cement causes the emission of harmful pollutants such as CO_2. It is said that 1 tonne of cement production emits approximately 1 tonne of CO_2. Thus alternative materials have to be used to replace the conventional Portland cement in order to minimise the liberation of CO_2 into the atmosphere. Hence geopolymer concrete is one such material which completely replaces the cement by waste materials such as GGBS, fly ash etc. In this study, four HSTVC and four HSGPC slabs with partially restrained supports are analysed using a mechanical software called ANSYS V16.2. The reference for this work was taken from the experimentally done project which was carried out for the above considered slab models with the same partially restrained supports. The grade of concrete used for both the slabs are M60. The slabs are analysed to study the flexural behaviour and ultimate strength and test results obtained are then compared with the experimental values.

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II. OBJECTIVES

The following are the principal objectives of the current study:

A. To model HSTVC and HSGPC slabs for different spacing using ANSYS software.
B. To obtain various data from analysis of slabs namely max deflection, ultimate load, deflection at various stages of loading and to plot load vs. deflection graph.
C. To study the load-deflection behaviour and strength of GPC slabs and TVC slabs.
D. To compare the results obtained for TVC slabs and GPC slabs with experimental values.
E. To find the load enhancement beyond Johensen's yield line load.
F. To prove that the properties of GPC are similar to conventional concrete.

III.METHODOLOGY

Intension of the current study is to carryout FEM analysis on all these eight slabs and to compare the results with experimentally obtained results. A discrete model technique was employed to generate the finite element version. ANSYS V16.2 was utilised in the current study to check the overall behaviour of all the slabs.

A. FEM inputs for concrete

Table I
Density, Cube Compressive Strength, Young's Modulus And Poisson's Ratio For Concrete

Slab Designation	Density	Cube Compressive Strength (f_{ck})(MPa)	Elastic Modulus $E_c=5000\sqrt{f_{ck}}$ (MPa)	Poisson's Ratio
TVC1	2400	66	40620.19	0.2
TVC2	2400	65	40311.2887	0.2
TVC3	2400	67	40926.76	0.2
TVC4	2400	63	39686.2697	0.2
GPC1	2700	64	40000	0.16
GPC2	2700	66	40620.19	0.16
GPC3	2700	67	40926.76	0.16
GPC4	2700	67	40926.76	0.16

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B. Geometry of the Slabs

All the slabs used here were of size 1500mmX1000mmX65mm with partially restrained supports. An effective size of the slabs between the supports was taken as 1400x900x65mm. Slabs were reinforced with 6mm diameter Fe550 grade TOR-KARI bars. An effective cover of 20mm was given to the reinforcements. The reinforcement along longer direction is kept as 150mm and along shorter direction it is varied as shown in the table 2.

TABLE II Reinforcement Details

Sl. no	Specimen designation	Dia of Bar (mm)	Spacing of bars in (mm)		Percentage of reinforcement (%)		Coefficient of Orthotropy
			Shorter Direction	Longer direction	Shorter Direction	Longer direction	
1	TVC-1	6	150	150	0.26	0.26	1.00
2	TVC-2	6	120	150	0.30	0.26	0.86
3	TVC-3	6	100	150	0.39	0.26	0.67
4	TVC-4	6	85	150	0.48	0.26	0.54
5	GPC-1	6	150	150	0.26	0.26	1.00
6	GPC-2	6	120	150	0.30	0.26	0.86
7	GPC-3	6	100	150	0.39	0.26	0.67
8	GPC-4	6	85	150	0.48	0.26	0.54

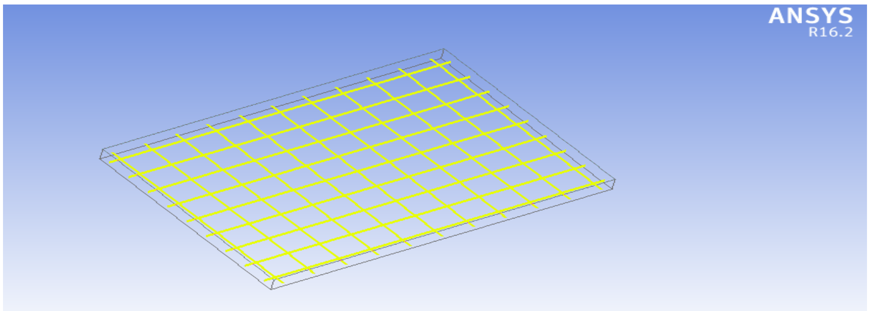

Fig. 1 Combined model with varied reinforcement spacing along shorter direction

C. Connections

The connection between the concrete and steel element is given through No-separation which acts as bond between them.

D. Convergence Criterion

The convergence study was carried out on models to check the mesh density. For this study a finite element model is to be divided into a number of discrete elements, and hence the result will converge only if proper numbers of elements are used. In the present study also a convergence study was conducted to determine the mesh density of the element.

E. Loading and Boundary Conditions

All the slabs were subjected to uniformly distributed loading throughout the slab area. The boundary condition is provided in such a way that one longer edge is fixed (i.e. restrained along all the three directions x, y and z) and all other three edges are simply supported (i.e. restrained along y and z directions) so that the downward displacement is detained at the supports.

F. Nonlinear solution

To carry out the nonlinear analysis in ANSYS, the total applying load need to be divided into number of intervals, which are called as load steps. Stiffness of the matrix will be adjusted after the completion of each load step. The alterations done in the stiffness matrix reflects the non-linear changes in the stiffness of structure after the end of each load step. The ANSYS software application uses Newton-Raphson iteration technique to update the stiffness of models. This approach has tolerance limits, which could be assigned for the convergence of each iteration.

IV. RESULTS AND COMPARISON

Load v/s deflection behaviour of both high strength traditionally vibrated concrete and high strength geo polymer concrete slabs from the analytical studies is tabulated as follows. And comparative study of parameters such as ultimate loads, load-deflection behaviour was carried out.

A. The maximum load and the corresponding deflection for different slabs in experimental work and in ANSYS showing nonlinear behaviour is as shown in the figure III & IV.

TABLE III
Ultimate Load And Deflection Results In Experiment

Slab designation	f_{ck} (Mpa)	P_u (kN)	δu (mm)
TVC-1	66	280	44.54
TVC-2	65	288.6	42.88
TVC-3	67	300.5	40.01
TVC-4	63	334.1	37.14
GPC-1	64	287.7	44.89
GPC-2	66	307.3	39.56
GPC-3	67	335.6	41.89
GPC-4	67	352.1	33.23

TABLE IV
Ultimate Load And Deflection Results In Ansys

Slab designation	f_{ck} (Mpa)	P_u (kN)	δu (mm)
TVC-1	66	313	44.573
TVC-2	65	303	43.05
TVC-3	67	302	40.092
TVC-4	63	300	46.428
GPC-1	64	310	44.859
GPC-2	66	278	39.808
GPC-3	67	295	41.27
GPC-4	67	260	46.474

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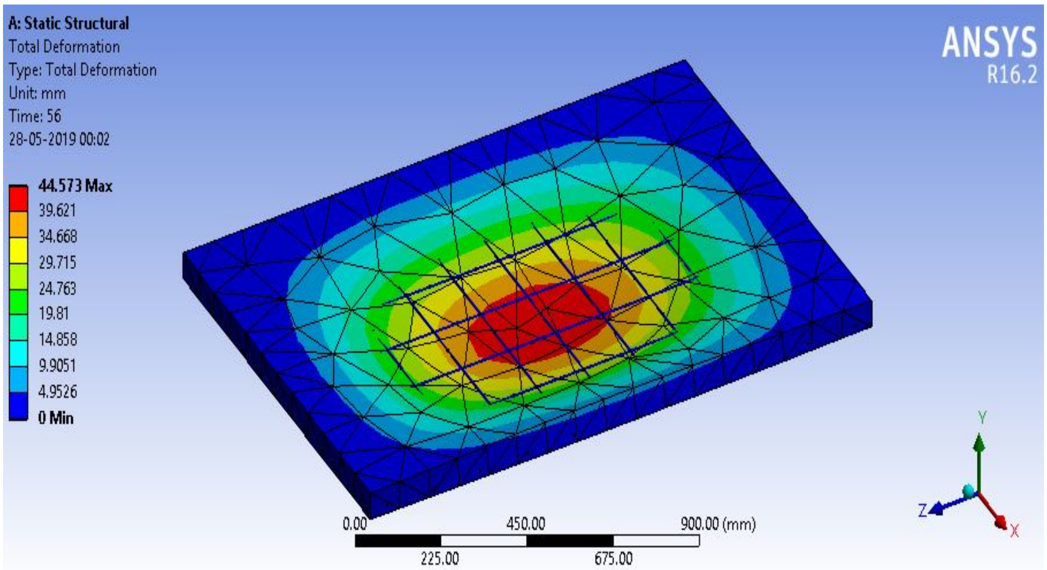
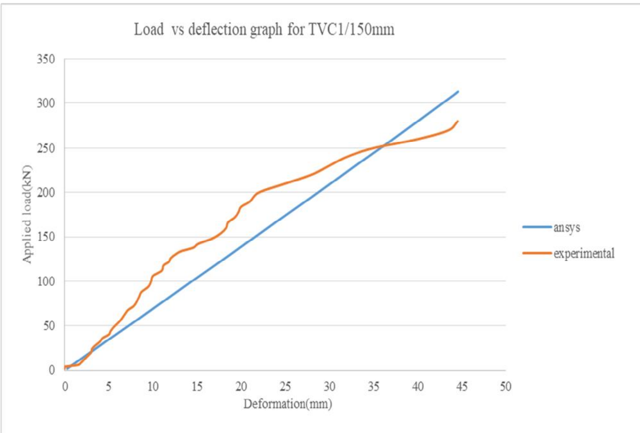


Fig. 2 Deflection behaviour of slab at ultimate load in ANSYS



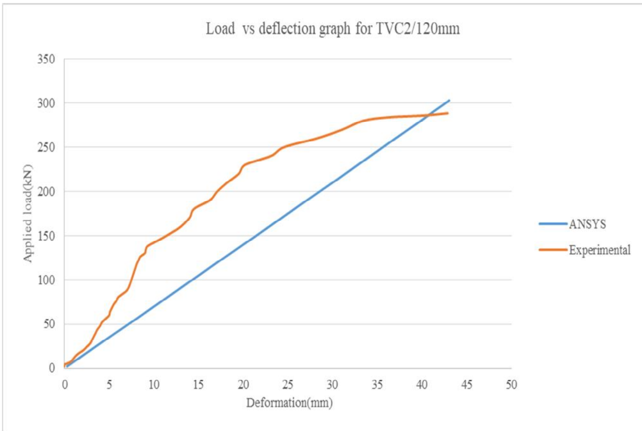
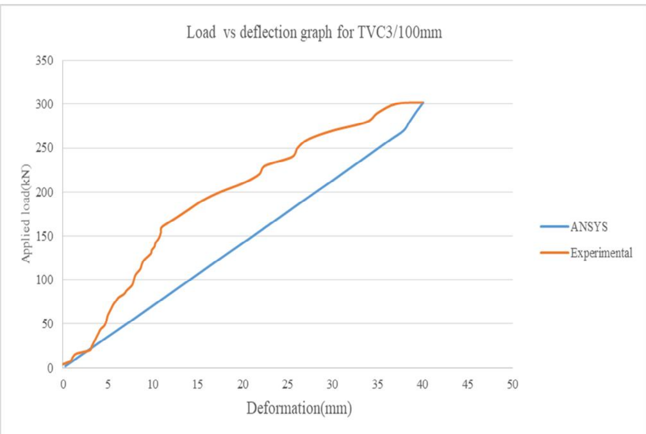


Fig. 3 Load- deflection curve for TVC1 slabs with 0.26% steel reinforcement. Fig. 4 Load- deflection curve for TVC2 slabs with 0.3% steel reinforcement.



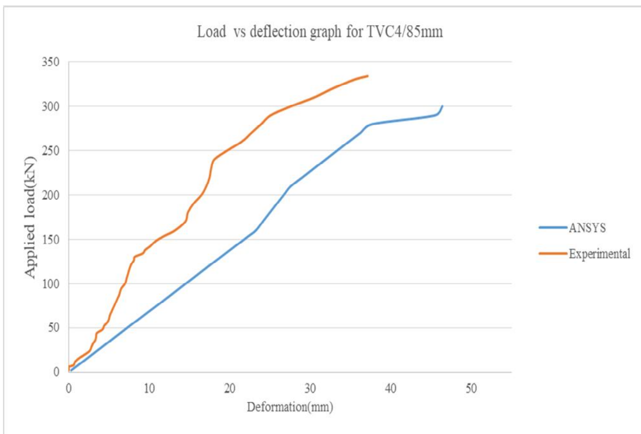


Fig. 5 Load- deflection curve for TVC3 slabs with 0.39% steel reinforcement. Fig. 6 Load- deflection curve for TVC4 slabs with 0.48% steel reinforcement.

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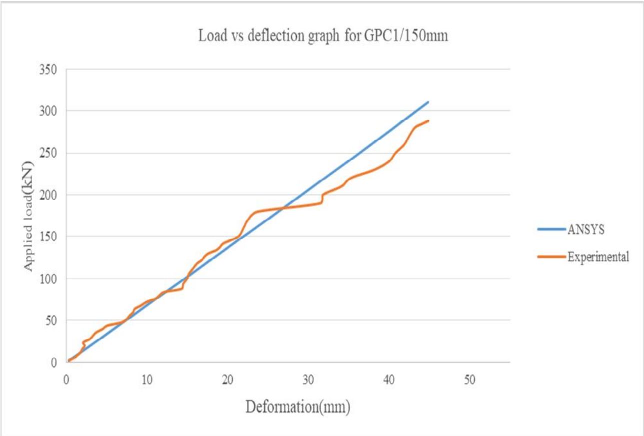


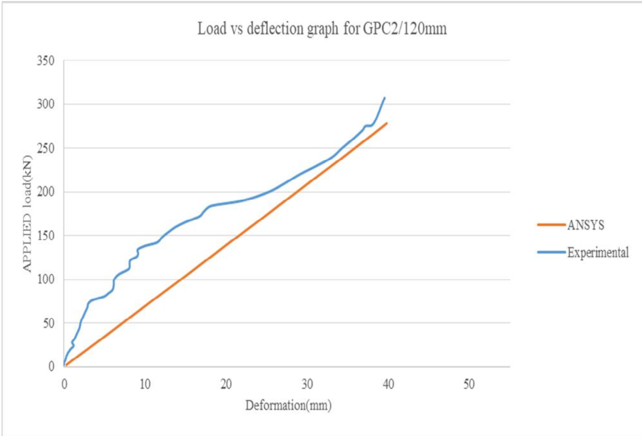
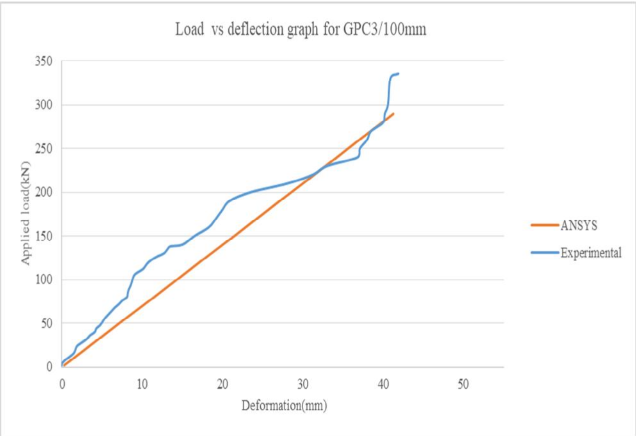


Fig. 7 Load- deflection curve for GPC1 slabs with 0.26% steel reinforcement. Fig. 8 Load- deflection curve for GPC2 slabs with 0.3% steel reinforcement.



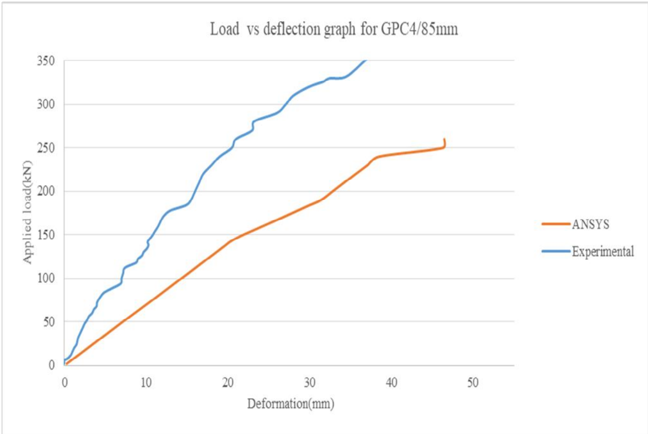


Fig. 9 Load- deflection curve for GPC3 slabs with 0.38% steel reinforcement. Fig. 10 Load- deflection curve for GPC4 slabs with 0.48% steel reinforcement

B. The maximum load and the corresponding deflection.

TABLE V
Percentage Of Steel Vs Ultimate Load Relation For Tvc Slabs

Percentage of steel	Slab	Ultimate load(KN)		EXP/AN
		Experimental (EXP)	ANSYS (AN)	
0.26	TVC 1	279.9	313	0.9
0.3	TVC 2	288.6	303	0.95
0.39	TVC 3	300.5	302	0.99
0.48	TVC 4	334.1	300	1.11

TABLE VI
Percentage Of Steel Vs Ultimate Load Relation For Gpc Slabs

Percentage of steel	Slab	Ultimate load(KN)		EXP/AN
		Experimental (EXP)	ANSYS (AN)	
0.26	GPC1	287.7	310	0.92
0.30	GPC2	307.3	278	1.1
0.39	GPC3	335.6	295	1.13
0.48	GPC4	352.1	260	1.3

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C. Comparison of load enhancement and load detraction.

TABLE VII
Comparison Of Load Enhancement And Load Detraction For Tvc Slabs

Percentage of steel	Slab	Johansen's Load, P_j (KN)	Ultimate load(KN)		Load enhancement and detraction $L=[P_U-P_j]*100/P_j$	
			Experimental	ANSYS	Experimental	ANSYS
0.26	TVC1	254.52	279.9	313	9.97%	22.97%
0.3	TVC2	263.42	288.6	303	9.56%	15.02%
0.39	TVC3	272.45	300.5	302	10.3%	9.78%
0.48	TVC4	278.13	334.1	300	20.12%	7.86%

TABLE VIII
Comparison Of Load Enhancement And Load Detraction For Gpc Slabs

Percentage of steel	Slab	Johansen's Load, P_j (KN)	Ultimate load(KN)		Load enhancement and detraction $L=[P_U-P_j]*100/P_j$	
			Experimental	ANSYS	Experimental	ANSYS
0.26	GPC1	254.50	287.7	310	13.05%	21.79%
0.3	GPC2	263.42	307.3	278	16.66%	5.53%
0.39	GPC3	272.45	335.6	295	23.18%	8.27%
0.48	GPC4	278.14	352.1	260	26.57%	-0.6%

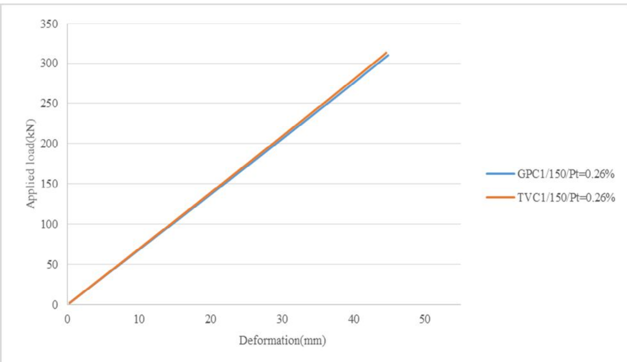

Fig. 11 Comparison for ultimate load between TVC1 and GPC1.

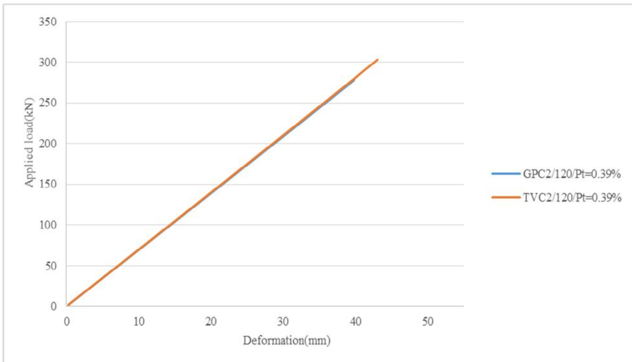

Fig. 12 Comparison for ultimate load between TVC2 and GPC2

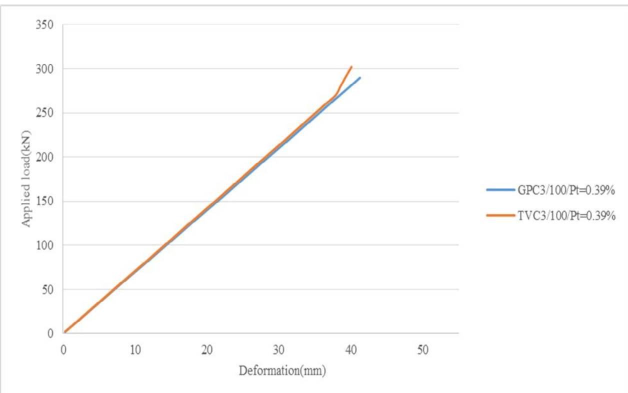

Fig. 13 Comparison for ultimate load between TVC3 and GPC3.

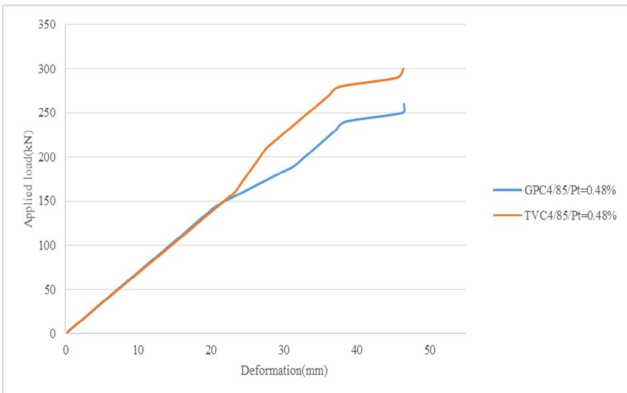

Fig. 14 Comparison for ultimate load between TVC4 and GPC4

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D. Comparison of Ultimate load for TVC and GPC Slabs

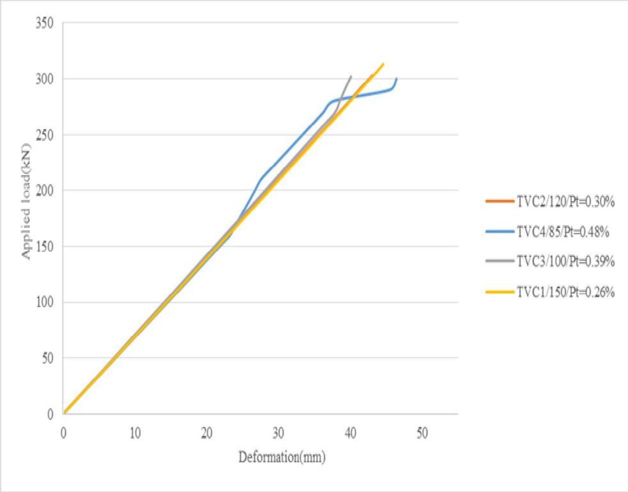

Fig. 15 Load vs deflection graph TVC slabs for various percentages of steel.

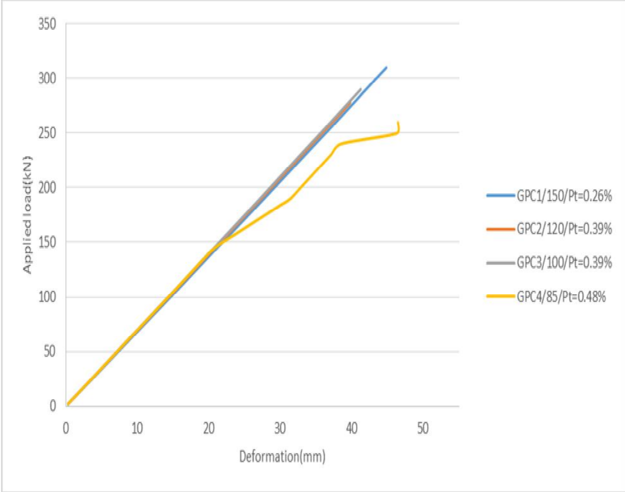

Fig. 16 Load vs deflection graph GPC slabs for various percentages of steel.

V. CONCLUSIONS

An analytical study was performed on two groups of reinforced concrete slabs; one of traditionally vibrated concrete and the other of geopolymer concrete with varied percentage of steel reinforcement. The effective dimensions of slab taken was 1400mmx900mmx65mm. This research was aimed to compare analytically obtained result with available experimental outcomes. Load deflection behaviour, ultimate load, load enhancement beyond yield load etc. were studied and compared.
Following conclusions were drawn from current study

- *A.* The ultimate loads obtained from ANSYS model for TVC slabs was varied from 0.5 to 11.33% higher than the experimental work. And for GPC slabs it was varied from 7.09 to 26.13% higher than experimental work. This may be attributed to the assumptions of perfect bond between the reinforcement and concrete in ANSYS model.
- *B.* It can be concluded that up to 30% of ultimate load the behaviour was linear and later nonlinear behaviour is observed due to reduced stiffness.
- *C.* The midspan deflections obtained from ANSYS have been lesser than that of experimental work for same magnitude of load. This may be due to the bond slip between the steel and concrete is disregarded in ANSYS.
- *D.* Deflection decreased as the percentage of reinforcement increased when compared to experimentally obtained result. In some slabs it showed increase in deflection.
- *E.* Ultimate load carrying capacity improved as reinforcement increased. This was consistent in both experimental and ANSYS as it is a expected behaviour of structural members. But in ANSYS it showed decreased load carrying capacity.
- *F.* Ultimate load carrying capacity was more in TVC slabs by 5% when compared to GPC slabs in ANSYS study, this is due to the fact that stiffness of the member reduces after the cracking loads up to ultimate load.
- *G.* Load enhancement beyond Johansen's yield line load was decreasing as percentage of reinforcement increased due to increase in load. This is due to the fact that stiffness of the member reduces after the cracking loads until ultimate load.
- *H.* The converged solution for the structural element will be realised only when small load steps are given because after initial cracking, the ANSYS results will not converge for greater load steps.

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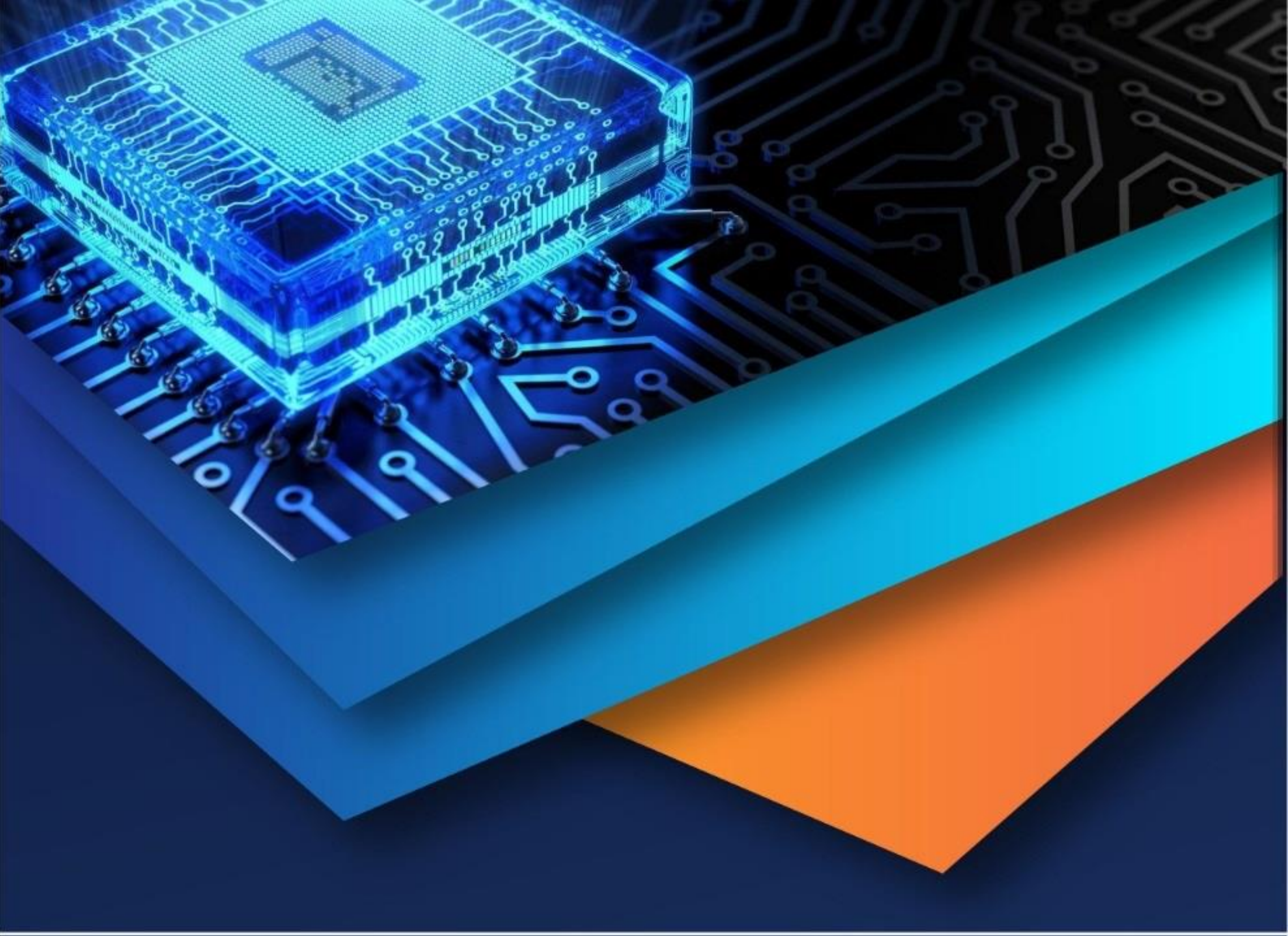

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