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Effect of Skew Angle on the Behaviour of Skew Slab under Uniformly Distributed Load

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Abstract— Slab is an extensively used structural element which usually carries uniformly distributed gravity loads. Out of different shapes of slabs, rectangular and skew slabs have quite a good number of applications in modern civil engineering structures. Skew slabs simply supported on two opposite side span can be divided into two types depending on the shape and the behavior of slabs. i) Skew slab with ratio of short diagonal to span less than unity and ii) Skew slab with ratio of short diagonal to span greater than unity. The use of FEA has been a preferred method to study the behavior of concrete structures as it is much faster than the experimental method and is cost effective. In this study finite element modeling of skew slab by using commercially available Finite Element software, ANSYS, has been carried out. Finite Element modeling of the skew slab (with short diagonal to span ratio less than unity) specimens with different skew angle has been done and the results obtained are compared. After the analysis it was found that maximum deflection of skew slabs decreases with increase in skew angle. This indicates that load carrying capacity of skew slab increases as skew angle increases.
Keywords— Reinforced concrete slab; skew slab; skew angle; Finite Element Analysis; Deflection of skew slab

I. INTRODUCTION

In a reinforced concrete structure, slabs are used to forming roof covering and floors of buildings and in bridges. Out of different shapes, rectangular and skew slabs have good number of applications in modern civil engineering structures. Normally, slab is perpendicular to the supports whereas skew slab is a four-sided slab having equal opposite angles other than 90^0. This shape of the slab facilitates a large variety of options for an engineer in terms of alignment opportunities in case of obstructions.

The behavior of a simply supported skew slab applied by point load at the centre depends on the ratio of short diagonal to its span. Skew slabs with short diagonal to span ratio less than unity show lifting of acute corners and slabs with short diagonal to span ratio greater than unity do not. This is because the reactions is act at the obtuse corner only when short diagonal to span ratio is less than unity and it is well within supports when short diagonal to span ratio is greater than unity.

Finite Element Analysis (FEA) is a method used for the evaluation of structures, providing an accurate prediction of the component's response subjected to various structural loads. The use of FEA has been a preferred method to study the behaviour of concrete structures as it is much faster than the experimental method. With the invention of sophisticated numerical tools for analysis like the finite element method (FEM), it has become possible to model the complex behaviour of reinforced concrete structures using Finite Element modeling. In this study finite element modeling of skew slab by using commercially available Finite Element software, ANSYS, has been carried out and compared with the available experimental results to validate the software. The study on effect of skew angle on behaviour of skew slab is examined here by varying skew angles from 0º to 60º.

II. GEOMETRIC PROPERTIES OF SKEW SLAB

In order to validate the analytical results of proposed approach, an experimentally tested skew slab (Flexural Behaviour of Reinforced Cement Concrete Skew Slabs by B.R Sharma) have been modeled in ANSYS with skew angle of 16.49^0. M 25 concrete have been used along with reinforcement pattern of 8 mm diameter bars @100 mm c/c is perpendicular to the support and distribution steel of 8 mm diameter bars @125 mm c/c laid over main reinforcement at right angles to it or parallel to the supports. Thicknesses of slabs have been kept 70 mm with clear cover 10 mm. The dimensions of the specimen are shown in figure 1.

To understand the effect of skew angle on the behavior of skew slab, a study was conducted on skew slabs with a reinforcement pattern of 8 mm diameter bars @100 mm c/c is parallel to the free edge and distribution steel of 8 mm diameter bars @125 mm c/c laid over main reinforcement at right angles to it or parallel to the free edge under different skew angles. ie, 0^0, 15^0, 30^0, 45^0,and 60^0.

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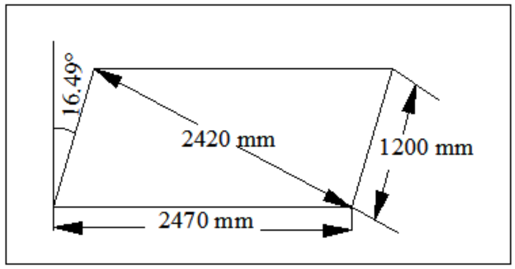

Fig.1 Dimensions of skew slab

III. FINITE ELEMENT METHOD

The Finite Element Method (FEM) is a numerical analysis for obtaining approximate solutions to a wide variety of engineering problems. The basic concept behind FEM is that a body or structure is divided into smaller elements of finite dimensions called ‘finite elements’. The original structure is then considered as an assemblage of these elements at a finite number of joints called ‘nodes’. A commercially available FEM Software called ANSYS of version 15 is used here for the finite element modeling.

A. Modelling

Selection of a suitable element types is an important criterion in Finite Element Analysis. For reinforced concrete slab the Concrete portion was modeled by using a special element namely SOLID 65 element. The element can be used to analyze cracking in tension and crushing in compression. This element has eight nodes, with each node having three translational degrees of the nodal X, Y & Z directions as shown in Figure 2.

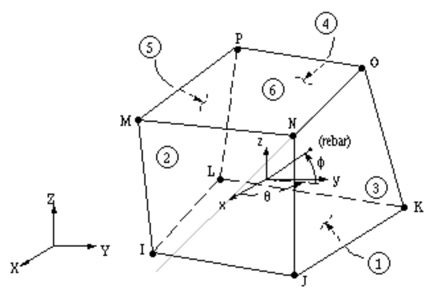

Fig.2 SOLID 65 Elements

Table 1

Material properties of solid 65 elements

Element Type	Material Properties	
SOLID65	Linear Isotropic	
	E_c	25000 MPa
	PRXY	0.2
	Concrete	
	Open Shear Transfer Coefficient (β_0)	0.2
	Closed Shear Transfer Coefficient (β_c)	0.9
	Uniaxial Cracking stress(ft)	3.5MPa
	Uniaxial Crushing Stress (fc’)	25 MPa

The reinforcement was modeled by using LINK 180 element. Depending upon the applications, the element may be thought of as a truss element, a cable element, a reinforcing bar and a bolt. This three-dimensional spar element is having two nodes and each node having three translational degrees of freedom as shown in Figure 3. This element is capable of plasticity, creep, swelling and stress stiffening effects. The cross sectional area of the element can be given as the real constant. The material properties provided are given in table 2.

Table 2
Material properties of link180 element

Element Type	Material Properties	
LINK180	Linear Isotropic	
	Ec	200000 MPa
	PRXY (ν)	0.3
	Bilinear Isotropic	
	Yield Stress (f_y)	415 MPa

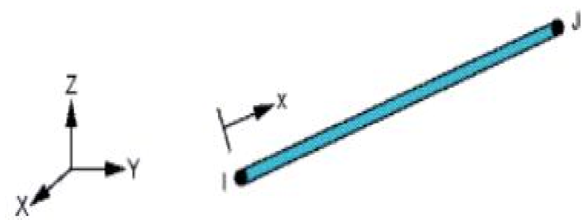

Fig.3. LINK 180 Element

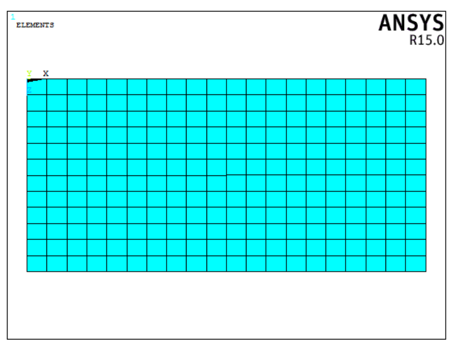

Fig.4 FE Model of skew slab with skew angle 0^0

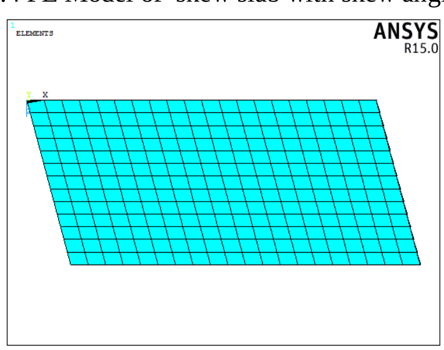

Fig.5 FE Model of skew slab with skew angle 15^0

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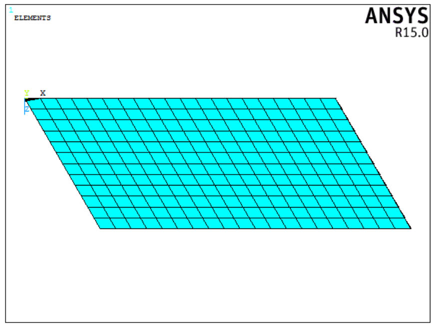

Fig.6 FE Model of skew slab with skew angle 30^0

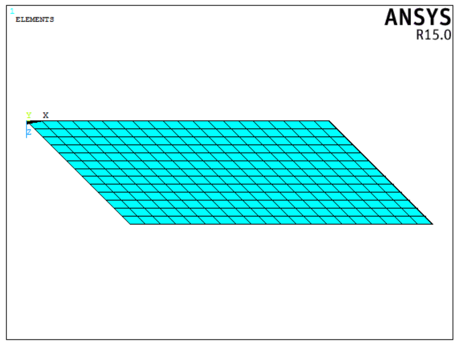

Fig.7 FE Model of skew slab with skew angle 45^0

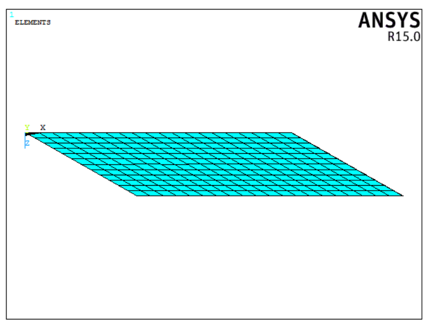

Fig.8 FE Model of skew slab with skew angle 60^0

B. Analysis

Displacement boundary conditions are needed to constrain the model to get a unique solution. To achieve this, the translations at the nodes UX, UY and UZ are restrained in order to obtain a hinged joint and translations at the nodes UY, UZ are restrained in right side in order to obtain the roller joint. The force or a gradually increasing load in the downward direction is applied at the top of the slab. The Static analysis type is utilized in this study. The Newton-Raphson method of analysis is used to compute the nonlinear response.

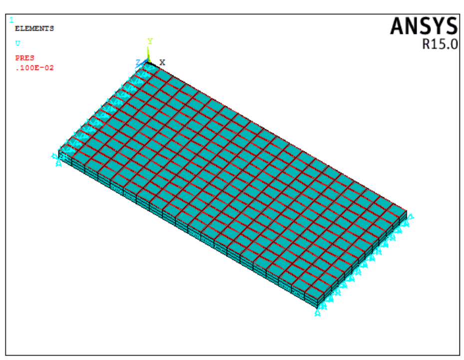

Fig.9 boundary condition of skew slab

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IV. RESULT AND DISCUSSIONS

The results of this study can be mainly included under 2 part such as the result of comparison of experiment and finite element analysis study and study of effect of skew angle on the behavior of skew slab.

A. Comparison of experimental and analytical results

To validate the obtained FEA results, comparison with experimental results are necessary. In the case of experiment, the load was applied gradually at the centre of the test specimen and deflections at the centre of the slab at different load are recorded. In FE Model of skew slab specimen, loads have been applied at the centre of the slabs as done in case of experiment. The load on the structure has been gradually increased in the steps till failure. The load-deflection values at every step have been recorded as in table 3

Table 3: Load and deflection from experiment and FE model

Load (kN)	Deflection (mm)	
	Experimental	Fe model
5	5.5	5.067
10	7.7	8.47
15	17	13.3875
20	24.7	20.67
25	29.3	25.75
26.4	-	29.1942

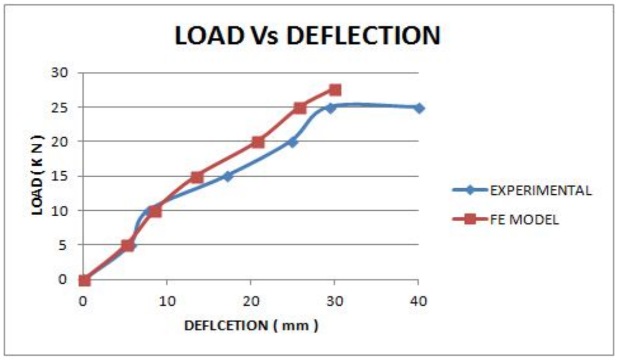

Fig.10 Load v/s Deflection comparison graph

From the plotted graphs in figure10, the FE model and Experimental results shows almost same results. It can be seen that the structure behaved linearly elastic up to the value of load 10kN. At this point minor cracks started to get generated. After this point there is slight variation in curvature in the plot and deflection started increasing. The ultimate load and corresponding deflection for FE model are 26.4kN and 29.1942mm respectively whereas the ultimate load and corresponding deflection came from experimental result was 25kN and 29.3mm respectively.

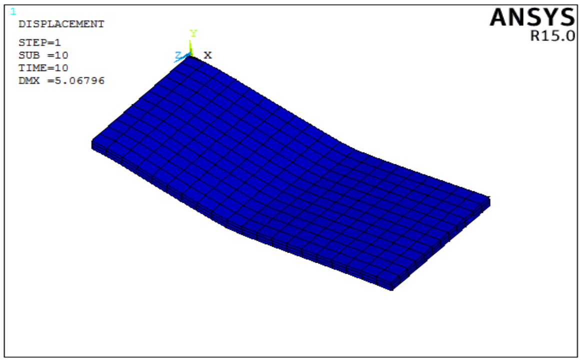

Fig.11 Deformed shape of skew slab at a load of 5Kn

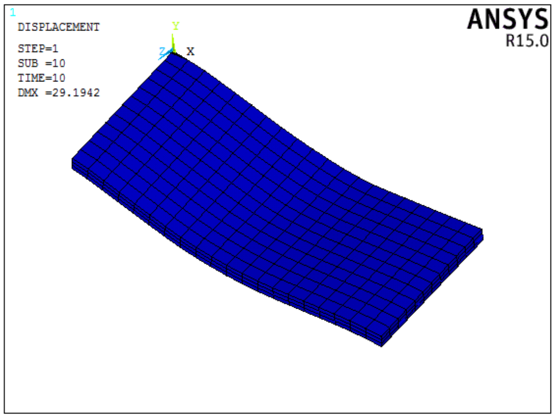

Fig.12 Deformed shape of skew slab at ultimate a load

B. Effect of skew angle on the behavior of skew slab

For studying the effect of skew angle on the behavior of skew slab, skew angles 0º (rectangular slab), 15º, 30º, 45º and 60º were considered with reinforcement pattern of main reinforcement parallel to free edge and distribution reinforcement perpendicular to the free edge. The uniformly distributed loads were applied up to ultimate load and graph of ultimate load v/s skew angle was plotted as shown in figure 13.

Table 4
Ultimate load for each skew angle

Slab with Skew Angles (in degrees)	Ultimate Load (kN/m^2)
0	14.8
15	21.3
30	30
45	48.5
60	85

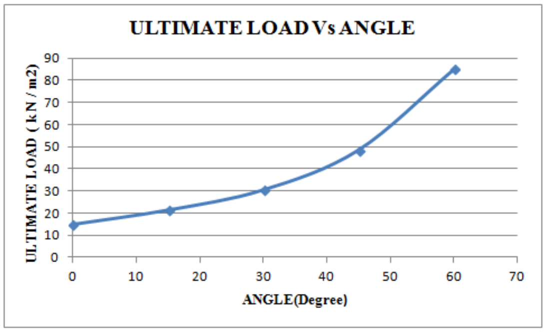

Fig.13 Ultimate load of skew slab with varying skew angle

It is observed that when skew angle increases from 0º to 60º the ultimate load carrying capacity of slab also increases.

Deflection corresponding to a constant load on skew slab with different skew angles shows that, as the skew angle increases the deflection decreases. It is graphically represent in figure 12

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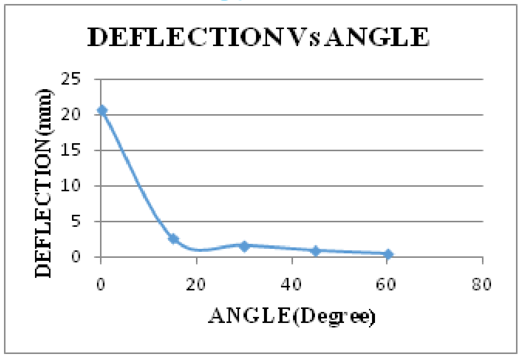

Fig.14 Deflection curve for skew slab with different skew angle

Deflections corresponding to different uniformly distributed loads were noted up to the ultimate load for skew slabs with skew angles 0º , 15º, 30º, 45º and 60º . Load v/s Deflection graph of skew slab for different skew angles were represent in figure 15

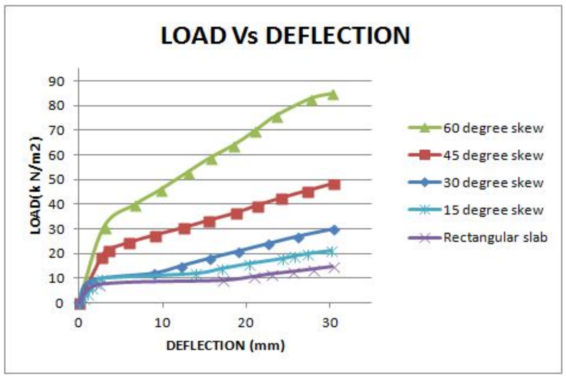

Fig.15 Load v/s Deflection graph of slab for different skew angles

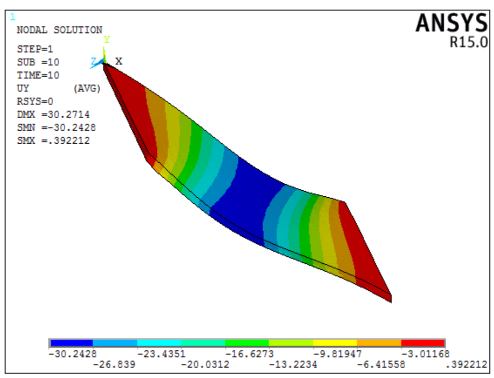

Fig.16 Displacement of skew slab with skew angle 60^0 in UY direction

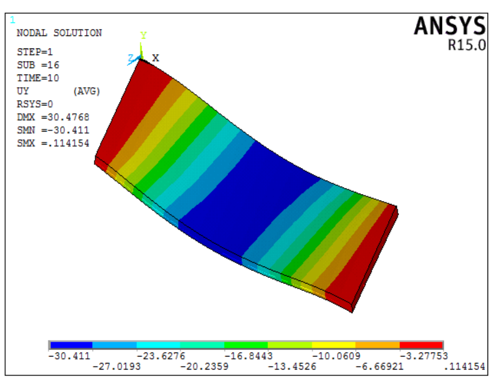

Fig.17 Displacement of skew slab with skew angle 30^0 in UY direction

This increase in load carrying capacity and decrease in deflection corresponding to increase in skew angle is because the maximum force flow between the support lines is through the strip area connecting the obtuse angled corners, as skew angle increases the length of strip area decreases.

V. CONCLUSIONS

In this study the behaviour of reinforced cement concrete skew slab with different skew angle under static load has been investigated. The following conclusions are obtained from the investigations

A. The general behavior of the finite element models represented by the load-deflection curves show good agreement with the experimental data. It is verified that the finite element analysis can accurately predict the load deformation similar to the experiment.

B. Maximum deflection of skew slabs decreases with increase in skew angle.

C. The load carrying capacity of skew slab increases as skew angle increases.

D. Up to skew angle 15º the behavior of skew slab is almost similar to rectangular slab.

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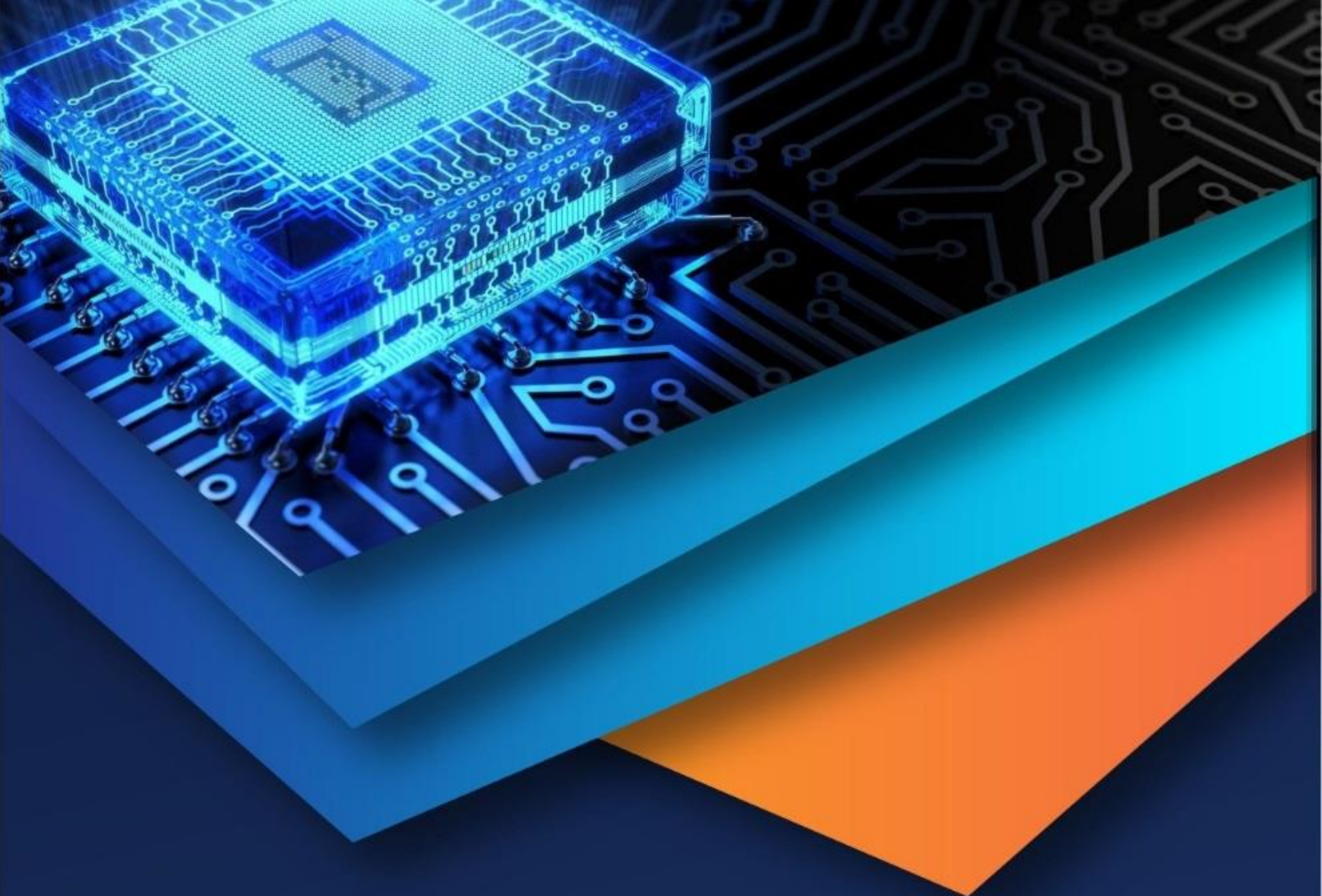

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