iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 8 Issue: XII Month of publication: December 2020

DOI: https://doi.org/10.22214/ijraset.2020.32526

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 8 Issue XII Dec 2020- Available at www.ijraset.com

A Numerical Analysis on Performance of Triangular Spin Fin Pile under Vertical Loading

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Abstract: Spin fin piles are simple circular pile fitted with flat, steel plates ("fins") attached at a slight inclination over the lower feet of the pile. A triangular spin fin pile is an alteration in ordinary pile where triangular shaped fins are welded to the outskirts of the monopile. The spin fin piles are utilized as foundation for offshore structures. The behavior of spin fin piles is hard to clarify utilizing simple pile–soil theories or two-dimensional mathematical investigations because of the complicated geometry of the piles. At the point when the piles are driven, these piles rotate into the ground and achieve pile capacities far in excess of conventional circular piles. In this paper the analytical investigation of the of triangular shaped spin fin pile foundation resting in sandy soil with respect to its various parameters is carried out. For this purpose, analytical model of spin fin pile is developed in MIDAS GTS NX software to simulate the pile foundation with different parameters proposed. A define soil model represent loose sand and medium dense sand with hollow steel triangular spin fin pile with inclined fins and with straight fins embedded within sand subjected to vertical loading. The fins increase the gross bearing area at the bottom of the pile and improve the end bearing capacity. As a result, the compressive capacity for spin fin piles can be achieved at shallow depths compared to similar sized conventional circular piles.
Keywords: Circular Pile, Triangular Spin Fin Pile, Pile Soil Theory, Vertical Loading, MIDAS GTS NX,

I. INTRODUCTION

Piles are usually acts as supporting structures for various large structures like very tall buildings, framed buildings, transmission towers, offshore structures etc. Monopiles are widely used to support offshore and onshore wind turbines. Large diameter of piles is required because of presence of weak soil and less over burden soil pressure carrying capacity by the pile near the top portion. Improvement in the load carrying capacity of pile can be enhanced by providing fins near the top or bottom part of the conventional circular pile, this new modified pile is called as Spin Fin pile. A Spin Fin pile is defined as a pile that has plates welded along the length of conventional circular pile at 90° to each other. Spin fin piles are most commonly used to provide resistance for large tensile and compressive forces. The geometry of the fins is such that when viewed from bottom the top of one fin meets the bottom of the adjacent fin, thus it provides 360^0 coverage. The angled "fins" cause the pile to rotate slightly as it is driven into the soil profile.

II. LITERATURE REVIEW

K.V. Babu *et al.* (2018)[1] carried out analysis on Lateral Load Response of Fin Piles. They carried out numerical model studies on the lateral load response of regular piles (pile without fins) and fin piles in sand. Three-dimensional finite element analyses were performed on regular piles as well as fin piles. Analyses were performed in sand with different relative densities, viz., 40%, 55% and 85%. Regular and fin piles having four and eight fins were considered during the analyses. The behavior of regular pile and fin piles with different sand relative densities, fin orientations, fin numbers and position were investigated in sand. They concluded that, at higher fin length, star fin piles carried more lateral load followed by straight and diagonal fin piles. Fins placed near the pile top provided more resistance than those placed near the pile bottom.

J. R. Peng *et al.* (2010)[2] carried out analysis on laterally loaded fin piles. A 3D computer simulation of laterally loaded fin piles was presented to explore the effect of fin dimensions on their load bearing capacity in sand. The behavior of fin piles was compared with the monopile using PLAXIS-3D software to generate the pile head P–Y curves. They concluded that lateral resistance increased with the increase in length of the fins. A fin pile had the optimum fin efficiency when the fin length is half the pile length. Fins placed near the pile top provided more resistance as compared to fins provided near the pile bottom.

Mohamed A. Sakr *et al.* (2019)[8] carried out analysis on single pile with triangular shaped wings in sand for uplift loading condition. A nonlinear 3D analysis with an elastic plastic soil model, an elastic pile material and interface elements were used to model the modified pile–soil interaction. A numerical study using finite element analysis PLAXIS- 3D was run on piles without/with wings.

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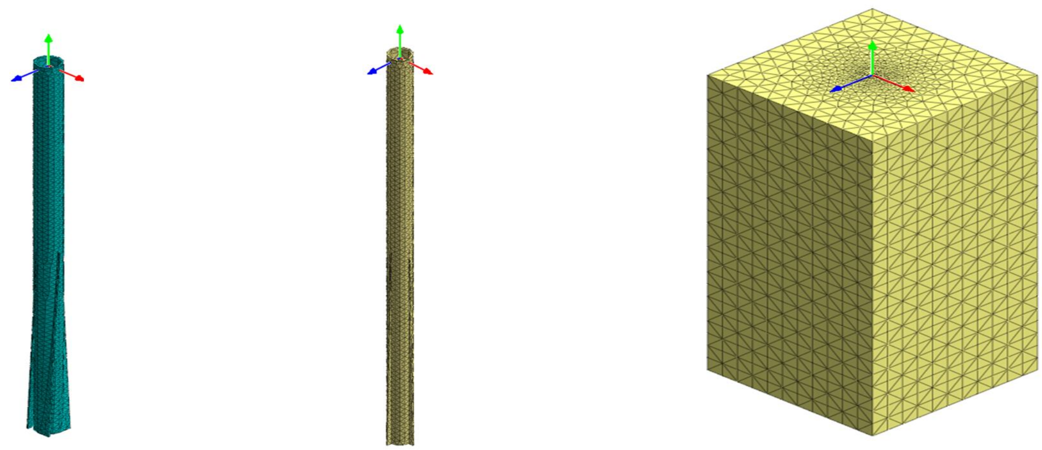
Studies were done by changing the wing-width ratio (D_w/d_p = 2, 3, 4 and 5), number of wings (n_w = 0, 2 and 4). The effects of sand relative densities were also considered. Results indicated that the adopted wings at the pile end have a considerable effect in increasing the uplift capacity with lesser deformation. It has been found that, for the same wing-width ratio (D_w/d_p), the wing efficiency for uplift capacity increases as the sand relative densities increase. For the wing width ratio (D_w/d_p of = 5) and number of wings of (n_w =4) the improvement in the uplift capacity are found to be (2.2, 2.33 and 2.45) times of normal pile without wings for sand density of (30%, 50% and 80%) respectively. The existence of such wings at the lower part of the piles was provided an ideal anchorage system because of the significant locking-up effect of the soils within the wings, resulting in increased uplift capacity.

III.METHODOLOGY

A three-dimensional finite element model was prepared in order to analyze the behavior of conventional circular pile and triangular spin fin pile with inclined and straight fins as shown in figure 1. The analyses were carried out using MIDAS GTS NX finite element software. The sand was assumed to be a linear elastic perfectly plastic material. A non-associated Mohr–Coulomb constitutive model was assumed to govern the soil behavior for which the material parameters are well established in geotechnical engineering practice. Soil block dimensions was taken as 22.5 times diameter of pile and 2.5 times length of pile. The bottom boundary was fixed against movements in all directions, whereas the 'ground surface' was free to move in all directions. The properties assigned to soil and the properties of pile are as shown in Table I,II and III respectively.



(a) (b) (c)

Fig. 1 a) Three-Dimensional View of (a)triangular Spin Fin Pile with inclined fins (b) triangular Spin Fin Pile with straight fins and (c) Sand Block

TABLE I
Properties Assigned to Soil

Properties	Unit weight	Relative Density	Young's modulus	Poisson's ratio	Angle of internal friction	cohesion
Symbols	γ	D_r	E	υ	Ø	c
Unit	kN/m^3	%	MPa		degree	kPa
Loose Sand	16.33	40	20	0.3	34	1
Medium Dense Sand	16.5	55	27	0.3	37.88	2

TABLE II
Properties Assigned to Soil

Sr. No.	Properties	Symbol	Values	Units
1	Young's modulus	E	2.0×10^8	kN/m^2
2	Density	ρ	78	kN/m^3
3	Poisson's ratio	υ	0.3	

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TABLE III
Properties Assigned to Pile Cap

Sr. No.	Properties	Symbol	Values	Units
1	Young's modulus	E	2.0×10^7	kN/m^2
2	Density	ρ	24	kN/m^3
3	Poisson's ratio	υ	0.15	

IV. NUMERICAL ANALYSIS

Analysis was carried out to evaluate the performance of triangular spin Fin Pile with inclined and straight fins and conventional circular pile embedded in sand. The analyses were conducted on model pile foundation and the parameters varied were type of soil, slenderness ratio and inclination angle of fins. The parameters viz., pile diameter, thickness and length of pile were kept constant. Details of parameters selected for analysis is given in Table IV.

TABLE IV. Details of Parameters Selected for Analysis

Sr. no.	Parameter	Constant parameters	Varying parameters
1	Diameter of pile	1.2 m	-
2	Dimensions for Fins	$L_f/L = 0.5$ $B_f/D = 0.5$	-
3	Thickness of Pile and Fin	0.075 m	-
4	Position of fins	At bottom of pile	-
5	Number of fins	4	-
6	Inclination of fin	-	0^o 82.40^o
7	Type of soil	-	Loose sand ($D_r = 40\%$) Medium dense sand (D_r=55%)
8	Length of Pile (m)	-	18,24,30
9	L/D of pile	-	15,20,25
10	Loading condition	-	Vertical loading

V. RESULTS AND DISCUSSIONS

The analysis was conducted on single conventional circular pile and triangular Spin Fin Pile subjected to vertical loading by considering different slenderness ratios (L/D=15,20,25). The comparison between triangular spin fin pile with inclined fins and straight fins were studied only for slenderness ratio (L/D) of 20. The load displacement curves for triangular spin fin pile with inclined fins and straight fins subjected to vertical load in loose sand and medium dense sand are plotted and are shown in figure 2 and figure 3 respectively. The load displacement curves for conventional circular pile and triangular spin fin pile subjected to vertical load in loose sand and medium dense sand are as shown in Figure 4 and Figure 5 for L/D=15, figure 6 and figure 7 for L/D=20 and figure 8 and figure 9 for L/D=25. The ultimate load capacity taken as the load corresponding to the displacement as per provisions of IS: 2911 (Part-4) 2013. The percentage increase in load carrying capacity of inclined fin and straight fin pile is shown in table V and percentage increase in load carrying capacity of circular pile and triangular spin fin pile is shown in table VI.

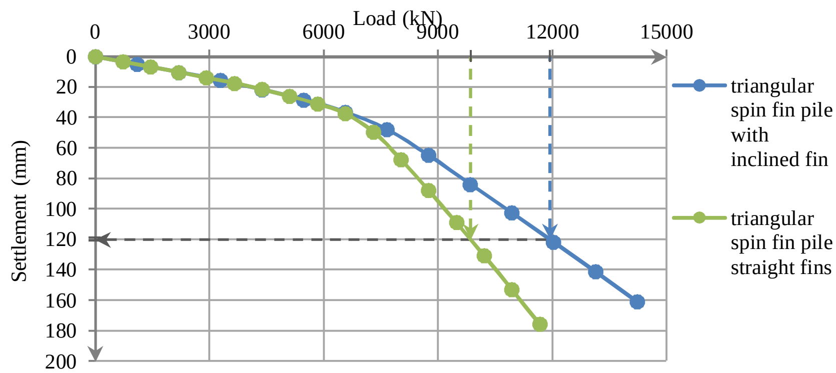

Fig 2. The load settlement curves for triangular spin fin pile with inclined fins and triangular spin fin pile with straight fins subjected to vertical load in loose sand for L/D=20

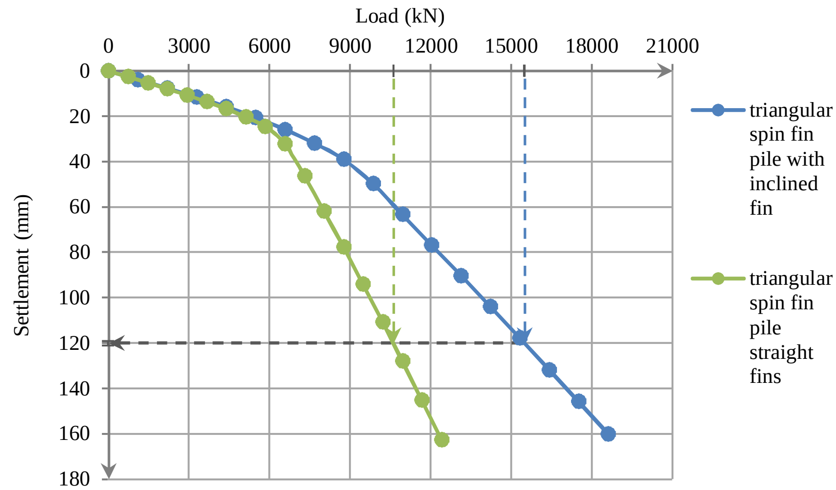

Fig 3: The load settlement curves for triangular spin fin pile with inclined fins and triangular spin fin pile with straight fins subjected to vertical load in medium dense sand for L/D=20

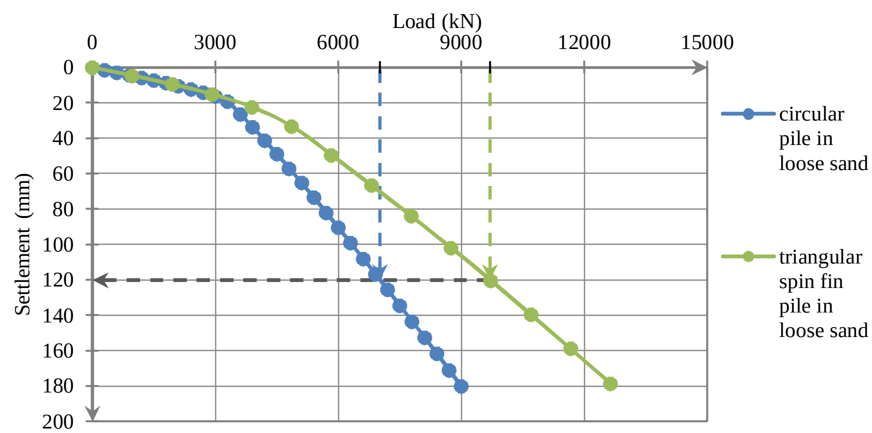

Fig 4: The load settlement curves for single circular pile and triangular spin fin pile subjected to vertical load in loose sand for L/D=15

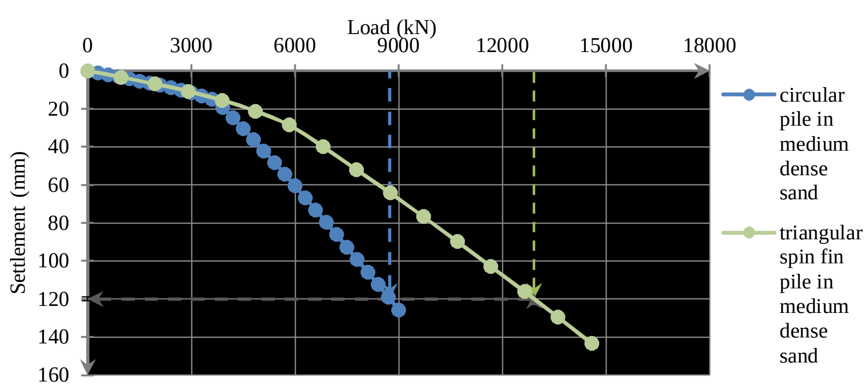

Fig 5: The load settlement curves for single circular pile and triangular spin fin pile subjected to vertical load in Medium dense sand for L/D=15

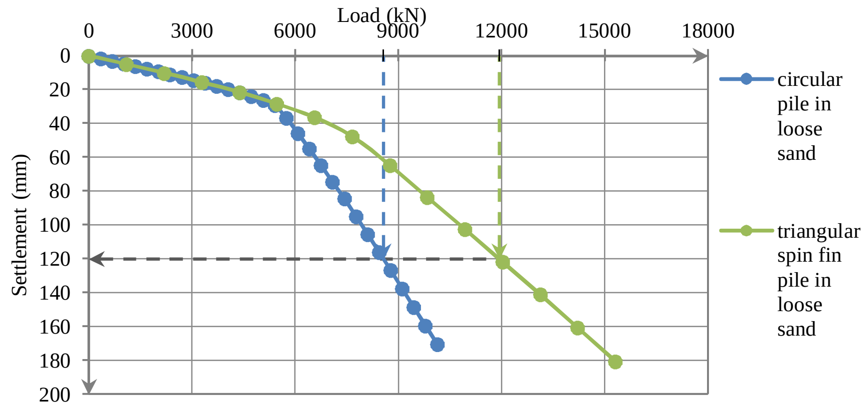

Fig 6: The load settlement curves for single circular pile and triangular spin fin pile subjected to vertical load in loose sand for L/D=20

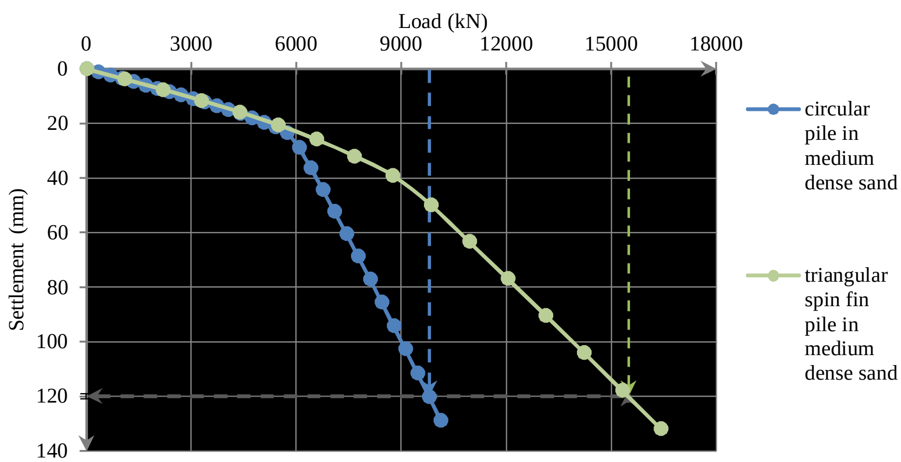

Fig 7: The load settlement curves for single circular pile and triangular spin fin pile subjected to vertical load in Medium dense sand for L/D=20

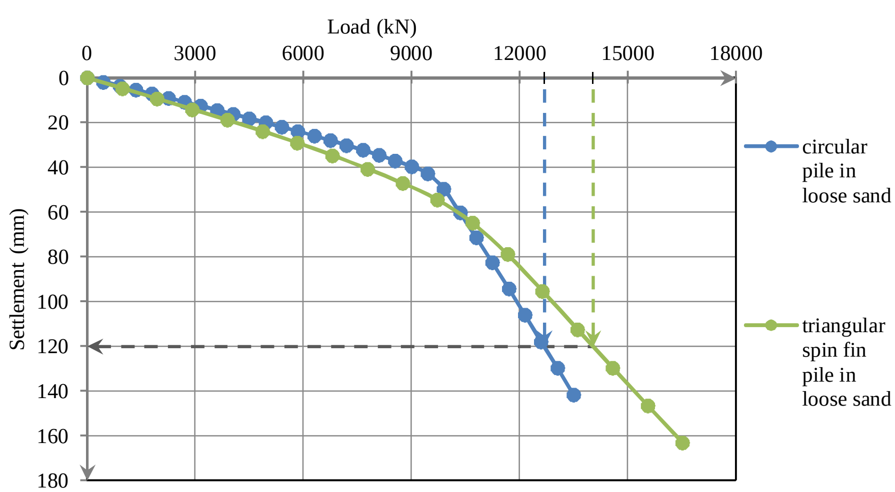

Fig 8: The load settlement curves for single circular pile and triangular spin fin pile subjected to vertical load in loose sand for L/D=25

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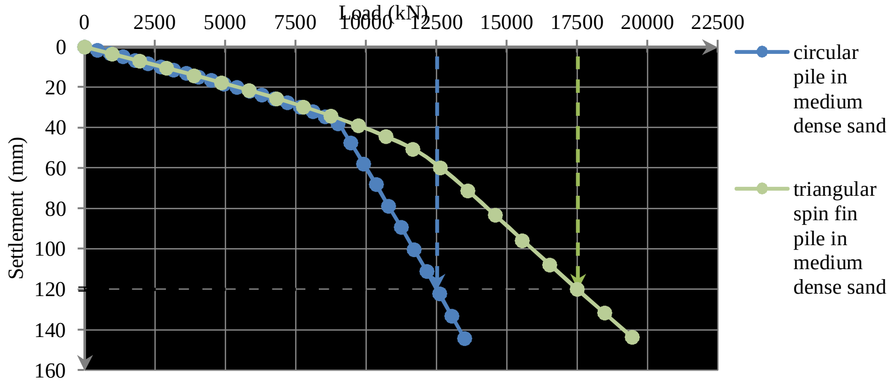

Fig 9: The load settlement curves for single circular pile and triangular spin fin pile subjected to vertical load in Medium dense sand for L/D=25

Table IV
Percentage Increase in Ultimate Load Carrying Capacity of Triangular Spin Fin Pile.

Type of Loading	Relative density of sand	L/D ratio of pile	Ultimate load capacity of triangular spin fin pile (kN)		% increase in ultimate capacity
			Inclined fins	Straight fins	
Vertical loading	Loose sand	20	11931	9846	21.1
	Medium dense sand		15482	10601	46

Table V
Percentage Increase in Ultimate Load Carrying Capacity of Pile

Type of Loading	Relative density of sand	L/D ratio of pile	Ultimate load capacity of circular pile (kN)	Ultimate load capacity of triangular spin fin pile (kN)	% increase in ultimate capacity
Vertical loading	Loose sand	15	7012	9698	38.30
		20	8565	11931	39.29
		25	12683	14040	10.69
	Medium dense sand	15	8743	12919	47.76
		20	9788	15482	58.17
		25	12522	17520	39.91

Values obtained from curves shown in figure 2, figure 3 are tabulated in table IV and figure 4, figure 5, figure 6, figure 7 figure 8 and figure 9 are tabulated in table V, from tables we can see that ultimate load carrying capacity of triangular spin fin pile with inclined fins is more than triangular spin fin pile with straight and conventional circular pile for all slenderness ratio considered for study for vertical loading. For lateral loading slenderness ratio of 20 gives maximum increase in percentage for loose as well as medium dense sand.

VI. CONCLUSIONS

In this paper a comparative analysis of conventional circular pile and triangular Spin fin pile has been carried out in order to determine the increase in resistance of piles with different L/D ratio against vertical loading in loose and medium dense sand. Based on the results of the present study, the following conclusions are drawn:

A. The vertical load carrying capacity of triangular spin fin pile with inclined fins is more than triangular spin fin pile with straight fins.
B. The vertical and uplift load carrying capacity of conventional circular pile increases by addition of triangular fins to it.
C. The vertical load carrying capacity of triangular spin fin pile with slenderness ratio L/D=20 can be adopted for loose sand as well as medium dense sand.

VII. ACKNOWLEDGMENT

I owe my sincere thanks to my dissertation guide, co-guide, Head of the Civil Engineering Department, Principal, Government College of Engineering Amravati and my family who has not only helped me, but also gave me the enthusiasm and encouragement in my every step. I am very much thankful for their help, support and guidance throughout the completion of the dissertation. With all respect and gratitude, I would like to thank all the persons who directly or indirectly co-operated, helped and encouraged me throughout the dissertation work period.

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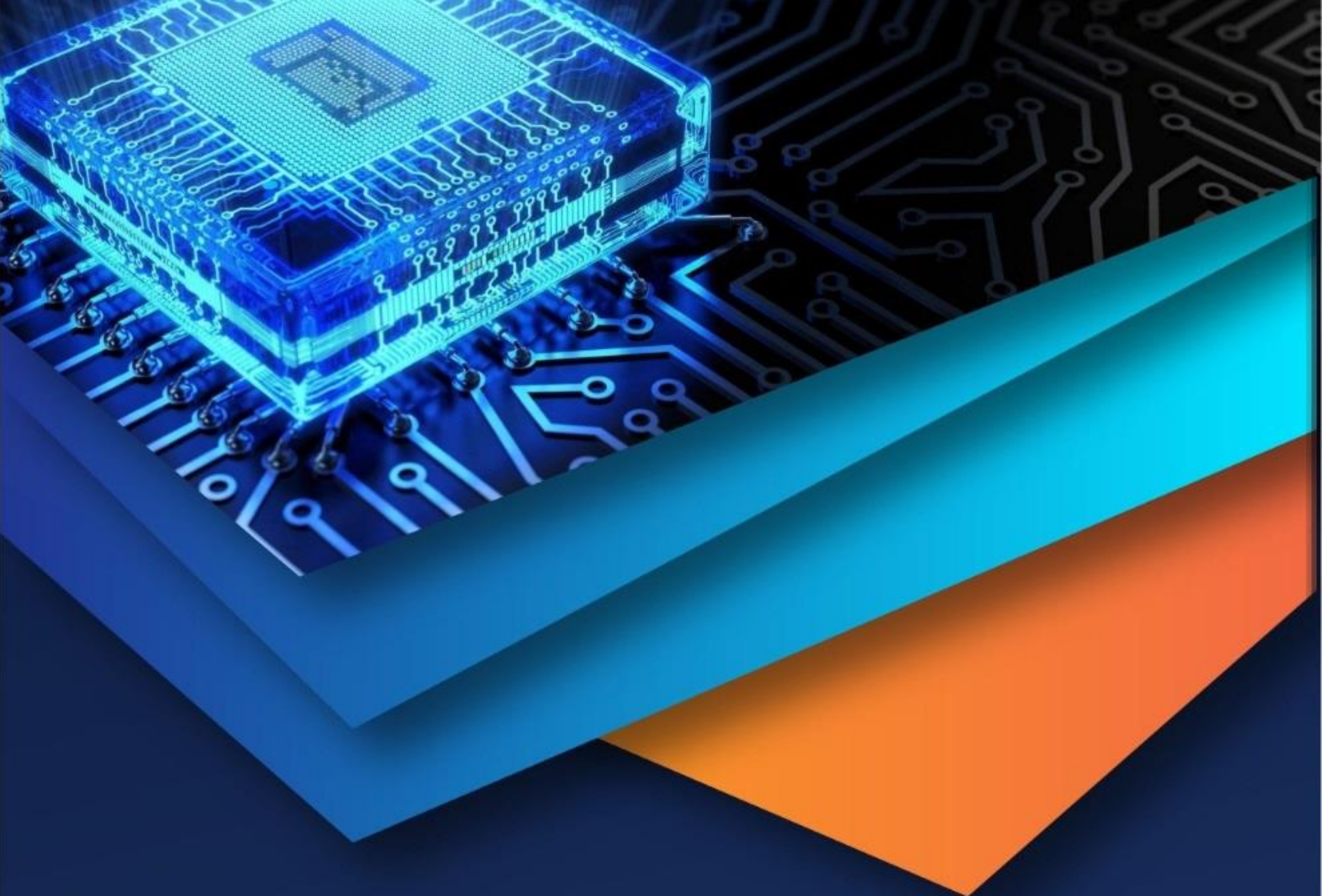

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