iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 7 Issue: I Month of publication: January 2019

DOI: http://doi.org/10.22214/ijraset.2019.1056

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 7 Issue I, Jan 2019- Available at www.ijraset.com

Numerical Analysis of Slope Stability- A Parametric Study

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Abstract: This research is contributing towards the community by suggesting very economical solution to minimize the landslide disaster. The main objectives of present study are, i) to carry out the parametric study on the behavior of slope for different cohesion, angle of internal friction, slope angle, unit weight and height of the slope. ii) to review past and current works in regards to Numerical and experimental modeling of slope. Methodology: For modeling of slope stability with different parameters, "GEO STUDIO – 2012" is used. Many parameters are varied in this analysis. Results and Conclusions: i) Initially, slope was modeled for different parametric studies. It was observed that, as the cohesion, angle of internal friction increased, factor of safety increased. ii) Also, when the slope angle and slope height was increased, factory of safety was decreased, leading to failure of slope tremendously. iii) We also observed that, change in unit weight of soil did not affect the stability of slope, as the shear strength of soil totally depends upon shear parameters such as cohesion and angle of internal friction.

Keywords: ***Landslides, Slope Stability, Cohesion, Angle of Internal Friction, Parametric Study***

I. INTRODUCTION

Slope is a measure of the steepness of a line, or a section of a line, connecting two points and a surface that lies at an angle to the horizontal so that some points on it are higher than others at an angle to a horizontal surface of 30°or part of the side of a hill or mountain. Slope can be defined as the angle, inclination, steepness, or gradient of a straight line. Slope often is used to describe the steepness of the ground's surface. Slope can be measured as the rise (the increase in elevation in some unit of measure) over the run (the horizontal distance measured in the same units as the rise). Many geographic information systems (GIS) can analyze digital elevation data (elevation points, contour lines, digital elevation models, etc.) and derive both slope and aspect data sets. Slope is an important landscape metric.

A. Slope stability Analysis

Slope stability analysis is performed to assess the safe design of a human-made or natural slope (e.g. embankments, road cuts, open-pit mining, excavations, landfills etc.) and the equilibrium conditions. Slope stability is the resistance of inclined surface to failure by sliding or collapsing.

The main objectives of slope stability analysis are finding endangered areas, investigation of potential failure mechanisms, determination of the slope sensitivity to different triggering mechanisms, designing of optimal slopes with regard to safety, reliability and economics, designing possible remedial measures, e.g. barriers and stabilization. Successful design of the slope requires geological information and site characteristics, e.g. properties of soil/rock mass, slope geometry, groundwater conditions, alternation of materials by faulting, joint or discontinuity systems, movements and tension in joints, earthquake activity etc. The presence of water has a detrimental effect on slope stability.

Water pressure acting in the pore spaces, fractures or other discontinuities in the materials that make up the pit slope will reduce the strength of those materials.

Choice of correct analysis technique depends on both site conditions and the potential mode of failure, with careful consideration being given to the varying strengths, weaknesses and limitations inherent in each methodology. Before the computer age stability analysis was performed graphically or by using a hand-held calculator.

Today engineers have a lot of possibilities to use analysis software, ranges from simple limit equilibrium techniques through to computational limit analysis approaches (e.g. Finite element limit analysis, Discontinuity layout optimization) to complex and sophisticated numerical solutions (finite-/distinct-element codes).

The engineer must fully understand limitations of each technique. For example, limit equilibrium is most commonly used and simple solution method, but it can become inadequate if the slope fails by complex mechanisms (e.g. internal deformation and brittle fracture, progressive creep, liquefaction of weaker soil layers, etc.). In these cases more sophisticated numerical modeling techniques should be utilized. Also, even for very simple slopes, the results obtained with typical limit equilibrium methods

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currently in use (Bishop, Spencer, etc.) may differ considerably. In addition, the use of the risk assessment concept is increasing today. Risk assessment is concerned with both the consequence of slope failure and the probability of failure (both require an understanding of the failure mechanism). Within the last decade (2003) Slope Stability Radar has been developed to remotely scan a rock slope to monitor the spatial deformation of the face. Small movements of a rough wall can be detected with sub-millimeter accuracy by using inter geometry techniques.

II. HIGHLIGHTS OF PREVIOUS RESEARCH

Researcher	Year	Content
Ali Fawaz et. all	2014	Slope stability analysis carried out to landslide that occurred during road excavation work in Lebanon using PLAXIS • dry season stable • presence of layers with varying permeability • triggering factor: rainfall • surface drainage
M. Rabie	2014	Focused on advantages of FE using PLAXIS in the analysis of slope stability problems over traditional LEM • no assumption of failure surface • stresses and strains • LEM are conservative • Saturated and unsaturated • FEM overestimated FOS
Dino Zuljani et.al.	2015	Parametric analysis of anchored bored pile wall as a part of landslide stabilization measures on the Grohovo road landslide, Croatia using Slide • 4 bore holes (inclinometers, piezometer) • max movement of 4mm towards toe • high water levels even in dry season • remedies: anchored bored pile wall, lowering GWT
Debarghya Chakraborty and Deepankar Choudhury	2009	Static and seismic analysis for a tailings earthen dam using FLAC, TALREN 4, SEEP/W and SLOPE/W • min FOS in static condition=1.22 (FLAC) • min FOS in seismic condition=0.89 (Talren-4) • kh=0.15 kv=0.075
Khadija Baba et. all	2012	stability was applied to a railway slope in Moroccon, of complex geometry, composed of alternating sandstone and marls using FEM and LEM • PLAXIS, GEO-SLOPE, and TALREN • no significant difference • advantages of FEM • FOS values of FEM are nearest to Bishop
Demin Xue et. all	2013	Numerical modeling of giant Badu landslide that reactivated by excavation in China using FLAC • Initially activated in 1994 • 76 piles with surface drainage • reactivated in 1997 due to heavy rainfall • Two grading retaining walls with surface & underground drainage
Ammar Rouaiguia and Mohammed A. Dahim	2013	Influence of pore water pressure, cohesion, internal friction angle, and unit weight of upper soil layer on the factor of safety for slope stability problems using GEO-SLOPE • FOS varies linearly with increase in cohesion, decrease in unit weight, pore water pressure • FOS varies non linearly with increase in φ
N. Hamdhan et. all	2013	Stability analysis of 11-m-high cut slope in Zaoyang, Hubei, China, subjected to rainfall infiltration. • PLAXIS • Infiltration caused decrease in metric suction, increase in moisture content & hydraulic conductivity • Displacements using FEM were more close to field conditions
Latifa Ouadif, et. al	2012	Stability study of this highway fill and compared the calculation results of the safety factor using LEM (GEO slope) & FEM (PLAXIS). • No significant difference in dry & saturation • Under seismic condition reduction in FOS using LEM is 30% • Using FEM it does not exceed 14%
Ahmad Safuan A Rashid	2013	Assessment of soil nailing performance by using FEM (PLAXIS) & FDM (FLAC) • Total excavation of 12m in 6 steps • FOS was higher for 1st & 2nd step by FDM • Good agreement was observed between both methods for 3rd to 6th step

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III. PARAMETRIC STUDY OF SLOPE STABILITY

Modeling of slope stability with different parameters using "GEO STUDIO SOFTWARE" The factor of safety is defined as the ratio of the available shear strength to the shear stress acting on the plane. The slope stability was carried out using Limit equilibrium analysis. Limit Equilibrium Method

1) Limit equilibrium investigate the equilibrium of soil mass tending to slide down under the influence of gravity
2) LEM is based on comparison of forces resisting of the mass and those that causing instability (disturbing forces).
3) Thus slope stability is usually expressed in terms of an index, most commonly the factor of safety, which is usually defined as

$$FS = \frac{\text{available shear strength}}{\text{shear } \textit{strength} \text{ required to maintain equilibrium}}$$

4) If FS = 1.5, then the slope is in critical condition.
5) If FS>1.5 the slope is stable
6) If FS<1.5 the slope failure is occurring

At the time of failure, the shear strength of the soil is fully mobilized along the failure plane.

A. Behavior Of Slope With Respect To Cohesion Of Soil

TABLE 3.1
Parameters adopted in model for effect of cohesion studies

Parameters adopted in model	Values
Cohesion (kN/m^2)	0, 25, 50, 75, 100
Angle of Internal Friction	35^0
Unit Weight (kN/m^3)	19
Height of Slope (m)	30 m (Approx.)
Angle of Slope (Degrees)	60

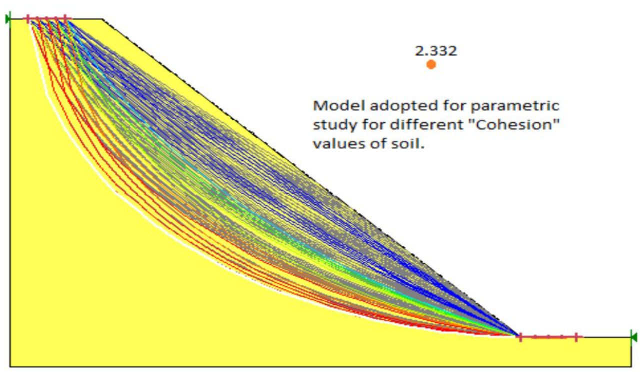

Fig. 1 Slope stability model for cohesion of soil 100 KN/m^2

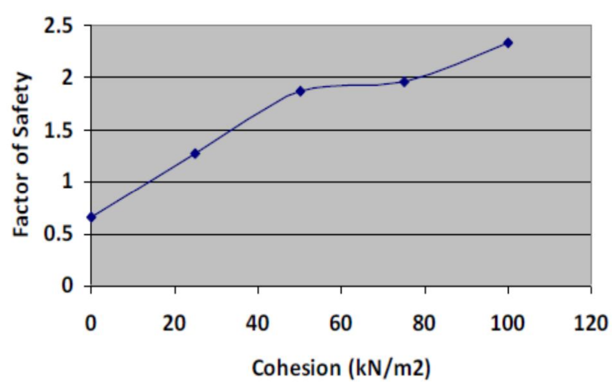

Fig. 2 Factor of Safety variation w.r.t. cohesion of soil

Factor of safety has direct proportional to the cohesion of soil, as cohesion of soil increases, factor of safety of slope increases.

B. Behavior Of Slope With Respect To Angle Of Internal Friction Of Soil

TABLE II
Parameters adopted in model for effect of angle of internal friction studies

Parameters adopted in model	Values
Cohesion (kN/m^2)	0
Angle of Internal Friction	24, 28, 32, 36, 40
Unit Weight (kN/m^3)	19
Height of Slope (m)	30 m (Approx.)
Angle of Slope (Degrees)	60

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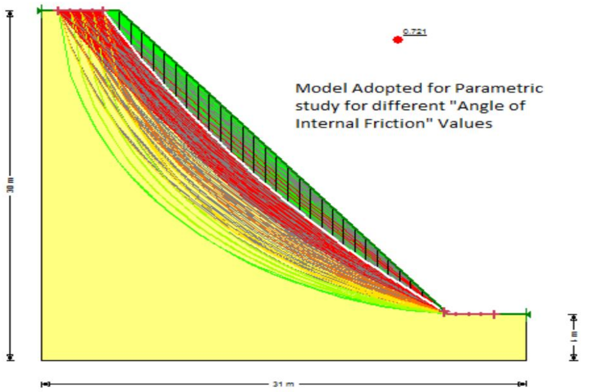


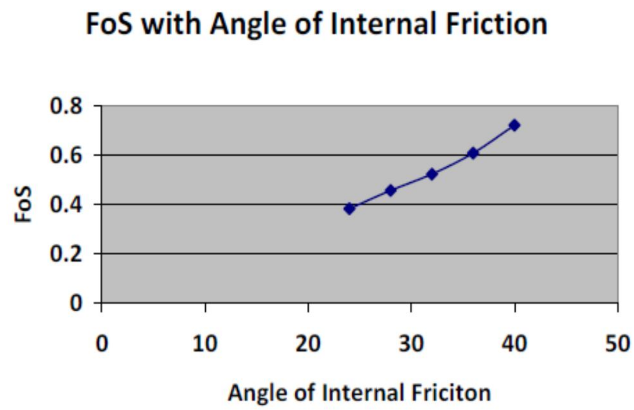


Fig. 3 Slope stability model for angle of internal friction of soil 40^0 Fig. 4 Factor of Safety variation w.r.t. friction angle

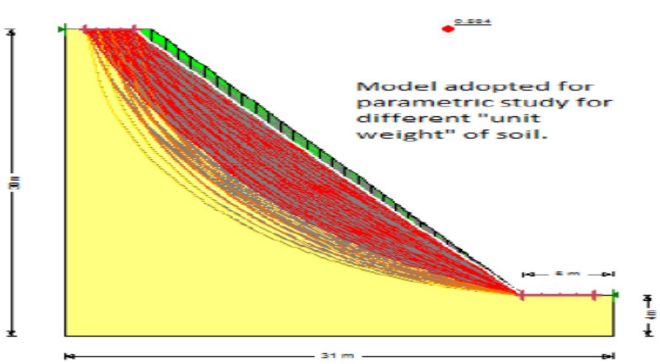
The angle of internal friction has directly proportional to the factor of safety, as angle of internal friction increases, the factor of safety also increases.

C. Behavior Of Slope With Respect To Unit Weight Of Soil

TABLE IIII

Parameters adopted in model for effect of unit weight of soil studies

Parameters adopted in model	Values
Cohesion (kN/m^2)	0
Angle of Internal Friction	35^0
Unit Weight (kN/m^3)	14, 16, 18, 20, 22
Height of Slope (m)	30 m (Approx.)
Angle of Slope (Degrees)	60



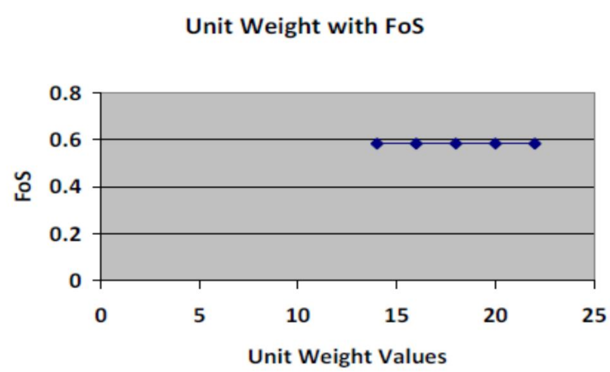


Fig. 5 Slope stability model for unit weight of soil Fig. 6 Factor of Safety variation w.r.t. unit weight of soil

Unit weight of soil does not have influence on slope instability. Because, in analysis of slope stability, strength of soil depends upon soil shear parameters such as, cohesion and angle of internal friction.

D. Behavior Of Slope With Respect To Height Of Slope

TABLE IIIV

Parameters adopted in model for effect height of slope studies

Parameters adopted in model	Values
Cohesion (kN/m^2)	0
Angle of Internal Friction	35
Unit Weight (kN/m^3)	19
Height of Slope (m)	10, 20, 30, 40, 52
Angle of Slope (Degrees)	50

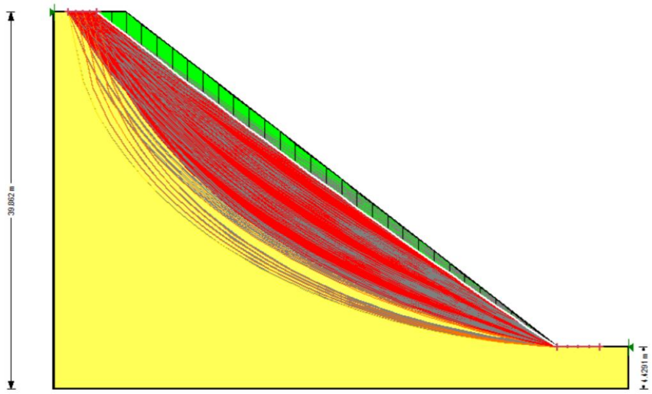


Fig. 7 Slope stability model for unit weight of soil

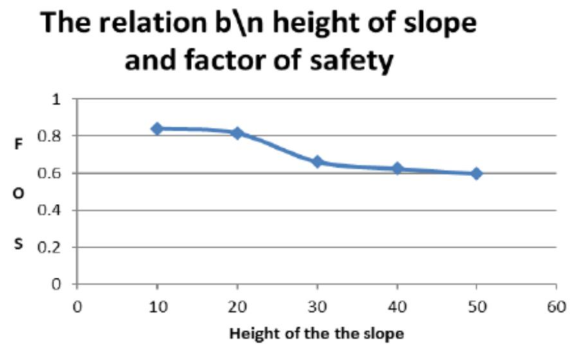


Fig. 8 Factor of Safety variation w.r.t. unit weight of soil

Factor of safety has inversely proportional to the height of slope of soil If height of the slope increases, the factor of safety decrease, because soil becomes unstable as shear strength of the soil reduces, as particles moves away from each other.

E. Behavior Of Slope With Respect To Slope Angle

TABLE V

Parameters adopted in model for effect angle of slope studies

Parameters adopted in model	Values
Cohesion (kN/m^2)	0
Angle of Internal Friction	35
Unit Weight (kN/m^3)	19
Height of Slope (m)	35
Angle of Slope (Degrees)	45, 50, 55, 60, 65

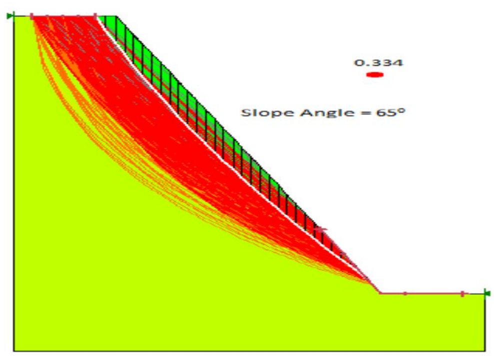


Fig. 9 Slope stability model for unit weight of soil

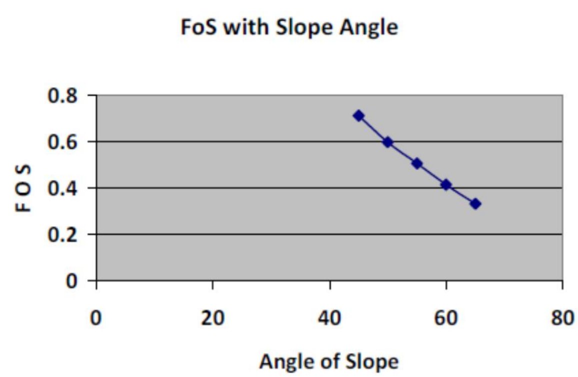


Fig. 10 Factor of Safety variation w.r.t. unit weight of soil

As the angle of slope increases, factor of safety of slope will start decreasing. Present soil, taken for modeling is poorly graded sand. This soil is loosely deposited in the slope. Friction between the particles is very less, which leads to slope failure.

IV. CONCLUSIONS

A. Initially, slope was modeled for different parametric studies. It was observed that, as the cohesion, angle of internal friction increased, factor of safety increased.

B. Also, when the slope angle and slope height was increased, factory of safety was decreased, leading to failure of slope tremendously.

C. We also observed that, change in unit weight of soil did not affect the stability of slope, as the shear strength of soil totally depends upon shear parameters such as cohesion and angle of internal friction.

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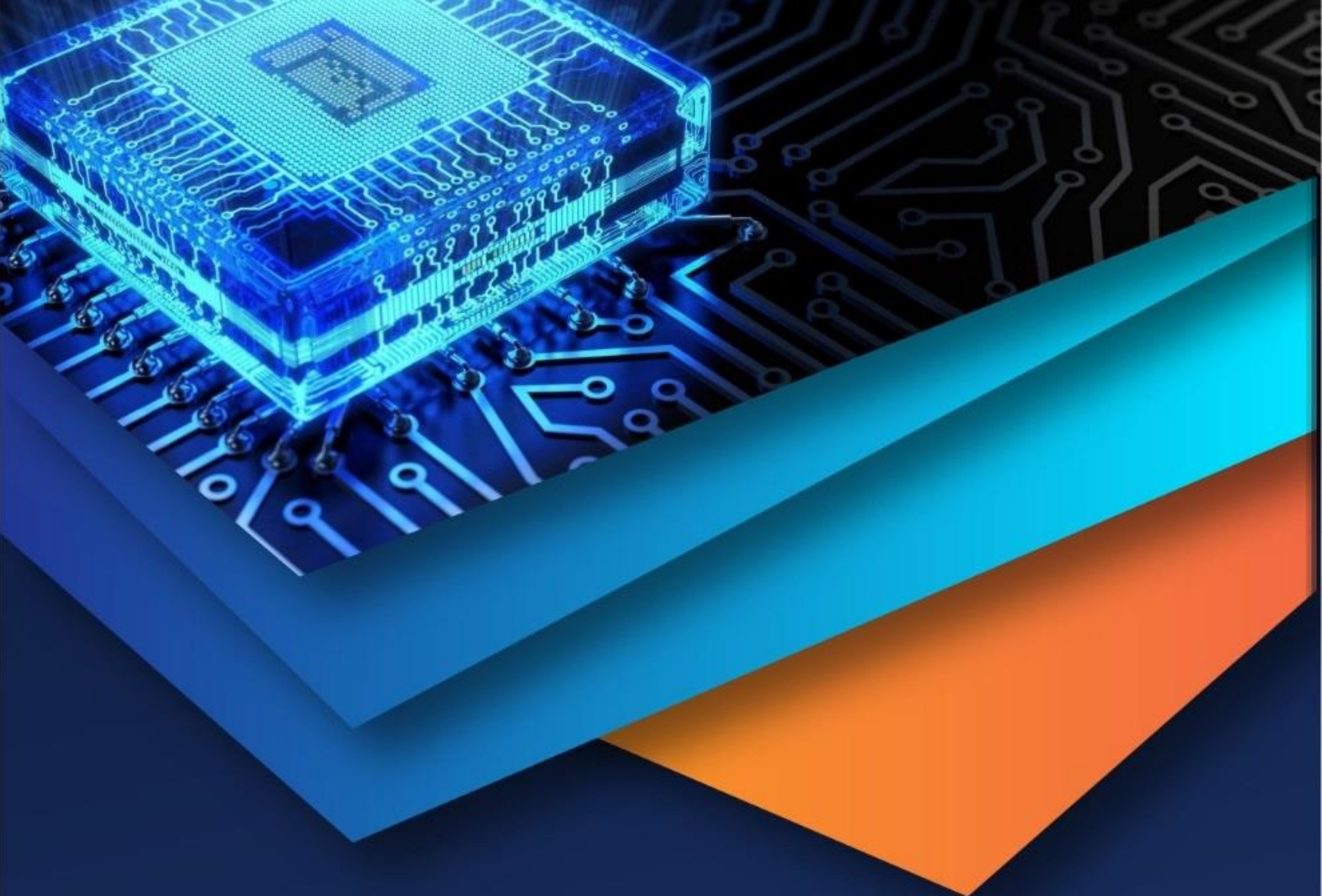

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