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Slope Stability Analysis of Highway Embankment with Different Height and Slope by Varying the Properties of Soil

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Abstract: The analysis of slope stability has received wide attention nowdays because of its practical importance. To provide steepest slopes which are stable and safe, various investigation are ongoing. The main objective of the project is to analyze slope of embankment by calculating factor of safety. So that an appropriate side slope can be chosen and use for the construction of highway. For this, limit equilibrium analysis has been done using GEO5 software. Swedish circle method (Graphically) has been used to performed manually analysis. In the present study, data collected from the site which is located near Shivni Village, Ner-Yavatmal road. "The construction of Samruddhi Mahamarg" is being constructed at that site. It is having high embankment heights upto 9meter. The values of unit weight of soil(γ), angle of internal friction(ϕ), cross sectional details of embankment and side slope of embankment were taken from that site. In this study, embankment of different heights (3 to 9m) under different 8 slopes (i.e. 1:2, 1:1.75, 1:1.5, 1:1.25, 1:1, 1:0.83, 1:0.7, 1:0.58), different values of cohesion and friction angle were considered. The analysis has been performed on two different cases: Case I stands for single layer of soil and Case II stands for double layer of soil by varying the value of cohesion and angle of internal friction the changes occur in the value of factor of safety were checked by comparing both results obtained by manual method and by GEO5 software. From this investigation it is found that increasing the value of cohesion and angle of internal friction, the factor of safety against slope stability increases. And for a particular height of embankment factor of safety increases with increase in the flatness of slope. From these results, it is better to use C-ϕ soil rather than ϕ soil as it gives maximum FOS as compared to sandy soil. From the analysis of doubled layered soil, it has been concluded that condition 2(with both soil cohesive) found satisfactory better with respect to condition 1(when one soil cohesive and one soil sandy). By considering condition 2 (both soil cohesive), it has been found that the increment of 25 to 30% in the FOS of condition 1 takes place.
Keywords: Road embankment stability, Factor of safety, Swedish circle method, GEO5 Software

I. INTRODUCTION

Slope stability is an important and delicate problem in civil engineering particularly for large projects such as dam, mining, highway, and tunnel. Many techniques exist for evaluation of slope stability. The main interest of slope stability analysis is typically to determine a factor of safety value against slope failure.

Slope stability analysis plays an important role not only in the construction of transportation facilities such as highway, railroads & canals but also the development of natural resources such as earth dams as well as many other human activities involving building construction & excavation. Failure of slope may be caused by movement within the human created cut or fill in nature slope or a combination of both. In man-made slope, properties of subsoil & fills soils are greatly effected on stability.

Slope stability analysis involves determining the shear stress developed along the most likely rupture surface & compare it with the shear strength of soil. The most likely rupture surface is critical surface that has the minimum factor of safety. The factor of safety depends partial in:

1) Property of terrain
2) Depth of trench and excavation (height of slope)
3) Position of ground water
4) Static and dynamic loading

Many alternative slope stability analysis methods have been proposed. In general slope stability analysis methods fall into two categories. The limit equilibrium method (LEM) & numerical method have been widely used. Limit equilibrium method further divided into slices method, Fellenius, Bishop Method. The limit equilibrium analysis is based on determining applied force & mobilized strength over a trail slide surface in the soil slope. Generally different LEM typically divide soil mass into many slices & assume different interslice normal & shear force in order to achieve a statically determine solution.

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Stability of high embankment depends on various factors like foundation profile, fill material quality, extent of compaction, drainage arrangement both surface and sub-surface and embankment geometry like height of embankment, slope angle, ground profile etc. External factors like traffic or earthquake load or presence of any water body by the side of the embankment or development of pore water pressure due to infiltration from heavy rain. All these parameters and conditions will make significant impact on overall stability of the embankment. Hence, it is very important to understand and evaluate these site specific conditions and interpretation of design parameters correctly before proceeding with design. The cost of earth work would be minimum if the slopes are made steepest. However, very steep slopes may not be stable. A compromise has to be made between economy and safety, and the slopes provided are neither too steep nor too flat. In the other words, the steepest slopes which are stable and safe should be provided.

A. Objectives of the Present Study

1) To understand the concept of Factor of safety.
2) To find out the relation between different parameters and factor of safety.
3) To get familiar with the different software used for slope stability purpose.
4) To learn the different methods used for the stability of slopes.

II. LITERATURE REVIEW

A wide range of slope stability analyses are performed using general purpose computer programs. There are many options and features to be considered such as soil strength and procedure analyses. Each of these options and features have sub combinations that lead to about thousands probable options and features for a comprehensive slope stability program.

Ashkan G Holipoor Noroozi, Alborz Hajiannia (2015): In the paper "The Effect of Cohesion and Level of Ground Water on the Slope Instability Using Finite Element Method," discussed about numerical analysis by finite element software PLAXIS version 8.5 showed that the slope angle and rainfall has the most influence in the safety factor analysis. Also for layered slope variable cohesion or friction angle for each layer has been investigated. The analysis has been done using Mohr-Coulomb constitutive model. From this, it is concluded that reduction of the height of ground water level causing the safety factor will be reduced to below 1.

Dorin-Vasile Moldovan, Andor-Csongor Nagy, Lavinia-Elena Muntean, Ciotlaus (2017): Worked on "Stability Of a Road Fill Embankment." This paper aims at making an analysis of the stability of a road fill embankment which related to a green landfill in the immediate vicinity of the Alba County. Stability analysis were performed with Geostru slope software and the sliding surface were calculated considering the limit equilibrium method. The result highlights the advantages and disadvantages related to any scenario and from the viewpoint of the stability factors as well.

Chunyuan Liu ,Ulysse Seho F. Hounsa (2018): Worked on "Analysis Of Road Embankment Slope Stability" and stated that the stability of earthwork (cuttings, embankment, dikes) and natural slopes is a problem that is of concern to geotechnicians, both practitioners and researcher. The disorders generated by breaking the slopes are usually spectacular; often destructive in these they have been proposed many methods of calculating stability. These are differentiated by the assumptions accepted by their authors. The main objective of this study is to present the problem of both natural and artificial slope stability on construction projects.

Vaibhav Garg, S.N Sachdeva (2019): Worked on "Analysis of Stability of Road Embankment Slope For Sandy Soil For Different Heights Of Embankment" they discuss the analysis of road embankment of different heights for sand soil under different variation of embankment slope. Four Embankments of different heights under four variation of slope were modelled in Geostudio 2018and the analysis is performed for the stability of slope of road embankment for different values of unit weight and friction angle of sandy soil by Bishop's method of slope stability using Geostudio 2018 software.

III. ANALYTICAL STUDY

In our present study, we visited the site located near Shivni village, Ner-Yavatmal road. The construction of Samruddhi Mahamarg is being constructed at that site. It is 8 lane highway, 4 on each side connecting the 10 major districts of Maharashtra. It is having high embankment heights up to 9 meter. In visit we collected various data from the site including unit weight of soil(γ), angle of internal friction(ϕ), cross sectional details of embankment and side slope of embankment they adopted. The main objective of the project is to analyze the slope of embankment by calculating the factor of safety (using various cases). For achieving this objective, the total experimental approach involved in this work has been divided into 2 different cases. For this work the additional data regarding the variation in soil properties(C & ϕ)has been taken from Soil Mechanics and Foundation Engineering by Dr. K.R. Arora and from the paper 'The effect of cohesion and level of groundwater on slope instability by finite element method' written by Ashkan G Holipoor Noroozi and Alborz Hajiannia. The details of the work in cases are narrated below.

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A. Analysis of Single Layered soil Embankment

1) *(Part A):* Analysis of Single layer embankment by considering and varying only angle of internal friction.
2) *(Part B):* Analysis of Single layer embankment by considering both Cohesion and angle of internal friction.

The problem has been solved by using Swedish circle method manually and by GEO5 software. For this, following steps has been conducted:

a) Formation of problem statement including slope angle, angle of internal friction, height of slope, type of failure, cohesion, unit weight of soil, etc.
b) Calculation of radius of critical circle by using correct direction angles α and β by Fellenius method.
c) Analyze the factor of safety by using Swedish circle method (graphically)
d) By varying the value of internal friction (ϕ) in part A and Varying both cohesion and angle of internal friction in part B (keeping all the parameters same), again calculate the factor of safety.
e) Solve the same problem using GEO5 software and calculate the factor of safety
f) After solving, comparing the results and discussion.

Firstly we have decided various height and slope for which a Factor of safety to be calculated. We have taken height of slopes from 3 meter to 9 meter and total 8 slopes were taken to calculate factor of safety. Following are the 8 slopes that have been taken.

Table 1 side slopes of embankment

1:2	1:1.75	1:1.5	1:1.25
1:1	1:0.83	1:0.7	1:0.58

In the part A we have only varied the value of internal friction. To check the change occurs in the value of factor of safety with increment in angle of internal friction. In this case we have solved problem only for single layered soil embankment. One single height of slope were given 8 different side slopes, 4 different ϕ values, only gamma value was kept constant and factor of safety were calculated.

for example: 1 height of slope * 8 slopes * 4 ϕ values = 32 problems for single height

32 * 7 total heights = 224 problems were solved in (part A)

From these problems, increments in the factor of safety with respect to ϕ were studied.

Following is the example solved for single layered soil embankment:

"An embankment having a slope ratio 1:1.25 and the height 5m.The possible circular failure surface is passing through the toe of cut slope. The properties of embankment soil are cohesion [C] = 0 kN/m², unit weight [γ]= 19 kN/m³ and angle of internal friction [ϕ] = 32°. Calculate the Factor of Safety for a given slope".

The problem above was solved using Swedish circle method by varying angle of internal friction and cohesion respectively.

In the part B we have varied both the value of angle of internal friction and cohesion. To check the change occurs in the value of factor of safety with increment in angle of internal friction and cohesion. In this case we have solved problem only for single layered soil embankment. One single height of slope were given 8 different side slopes, 4 different ϕ values (30,32,34,36) , 3 different cohesion values(10,20 and 30 kN/m^2), only unit weight value was kept constant and factor of safety were calculated.

for example: 1 height of slope * 8 slopes * 4 ϕ values* 3 cohesion = 96 problems for single height

96 * 7 total heights = 672 problems were solved in (part B)

From these problems, increment in the factor of safety with respect to ϕ and cohesion were studied.

B. Analysis Of Two Layered Soil Embankment

Analysis of embankment having 2 different layers of soil with varying cohesion value.

1) Formation of problem statement including angle of slope, height of slope, type of failure, unit weight, cohesion, angle of internal friction and soil layers.
2) Calculation of radius of slip circle by using correct direction angles α and β by Fellenius method.
3) Analyse the Factor of Safety manually by using Swedish circle method (Graphically).
4) By varying the cohesion in both layers and keeping all the parameter same, again calculate the Factor of Safety.
5) Solve the same problem by GEO5 software and calculate the factor of safety.
6) After solving comparing the manual and software results and discussion.

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In this Case-2, We have divided the embankment into 2 different layers of soil. Each layer containing different properties of soil. The first layer is provided at 50% of height of embankment. In this case, We have only varied the cohesion in both soil layers. To check the change occur in the value of Factor of Safety with increment in cohesion value. Each height of slope is divided into two different layers and were given 8 different side slopes, 2 different cohesion value, only the unit weight and ϕ were kept constant and factor of safety were calculated.

Generally in the construction of highway embankment, we use single soil to fill the embankment. We have adopted case 2 to check the variation occur in factor of safety after using two soil with different parameters.

Following is the example solved for double layered soil embankment:

"An embankment having slope of 1:1.25 and the height 5 meter. The possible failure surface is passing through the toe of cut slope. The first layer having 50% of overall depth of respective slope height with C= 0 kN/m² unit weight of 19 kN/m³ and ϕ is 32°. The second layer is also having 50% of overall depth of slope with C= 11kN/m² and unit weight of 20.2 kN/m³ and ϕ is 25°. Calculate the factor of safety by using Swedish circle method".

Given : Layer 1:C= 0kN/m², γ = 19kN/m³, $\phi = 32^o$

Layer 2: C= 11kN/m², γ = 20.2kN/m³, $\phi = 25^o$

Again by varying the value of cohesion of both the layers, the analyses were done.

C. Introduction to GEO5 Software

1) GEO5 is a powerful software suite for solving geotechnical problems based on traditional analytical methods and Finite Element Method (FEM). Individual programs verify a specific structure, which keeps them intuitive and easy to use.
2) GEO5 is designed to solve most geotechnical tasks, from the basic ones (verification of foundations, walls, slope stability), up to highly specialized programs (analysis of tunnels, building damage due to tunnelling, rock stability). Each GEO5 program solves definite structure type, so the customer can only select those he needs.
3) GEO5 is composed of individual programs with unified user interface, which is easy to use and does not require any special training.
4) Analytical verification methods provide effective and rapid structure design and verification. It is possible to transfer the analytical model into the FEM program, where the structure is verified by the finite element method. Comparison of two independent solutions contributes to increasing the safety and objectivity.
5) Educational license of GEO5 software is provided for educational purposes to schools, universities and other academic institutions at very favourable price. GEO5 Software is also supported by training materials which explain how a particular engineering problem can be solved in GEO5 software.

IV. RESULTS AND DISCUSSION

In the present study, limit equilibrium analysis were performed using GEO5 software. Swedish circle method were used to performed analysis manually. The analyses were performed on single layer of soil and double layer of soil with variation in slopes, height, cohesion and angle of internal friction. The factor of safety calculated manually and by software was reported in this chapter.

Table 2 Analysis considering different slopes with 5m height

Slope	Height	F.O.S(Manually)	F.O.S(GEO5)
1:2	5	2.24	2.15
1:1.75	5	1.94	2.03
1:1.5	5	1.66	1.70
1:1.25	5	1.53	1.55
1:1	5	1.31	1.36
1:0.83	5	1.20	1.22
1:0.7	5	1.09	1.12
1:0.58	5	1.06	1.04

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Figure 1 Slope angle vs factor of safety for 5m height

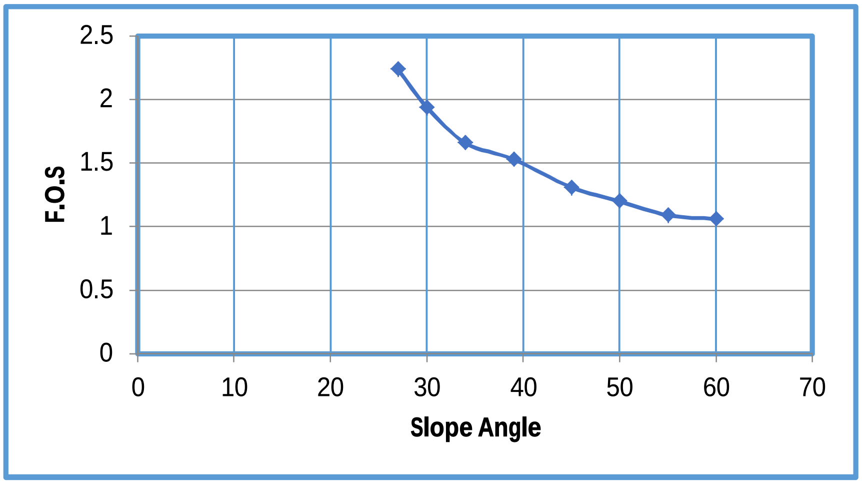
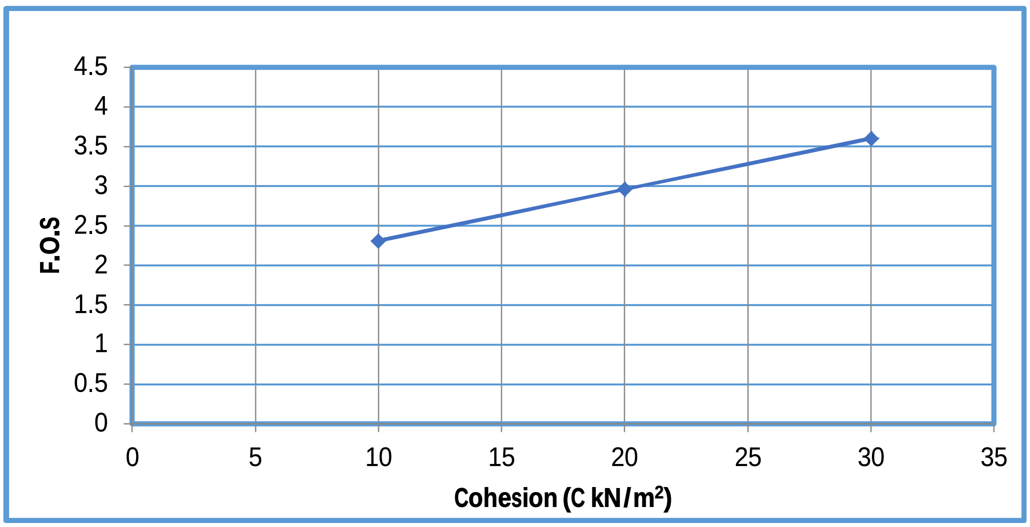


Figure 2 Cohesion vs factor of safety for 5m height



From the figure one we can conclude that the factor of safety increases with the decrease in side slope. Whereas figure 2 indicates that the cohesion plays important role in the factor of safety. The factor of safety increases with the increase in cohesion value. Factor of safety is directly proportional to the cohesion.

Figure 3 Angle of internal friction vs factor of safety for 5m height

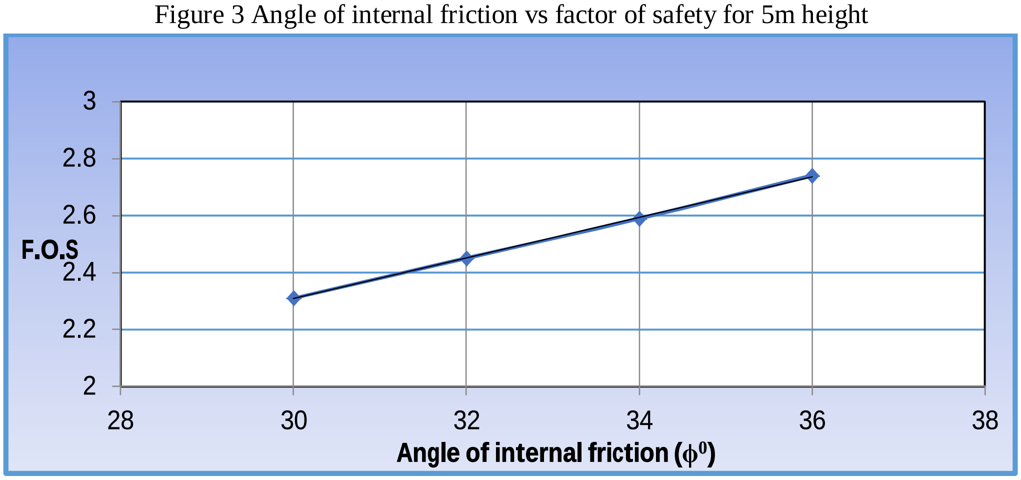


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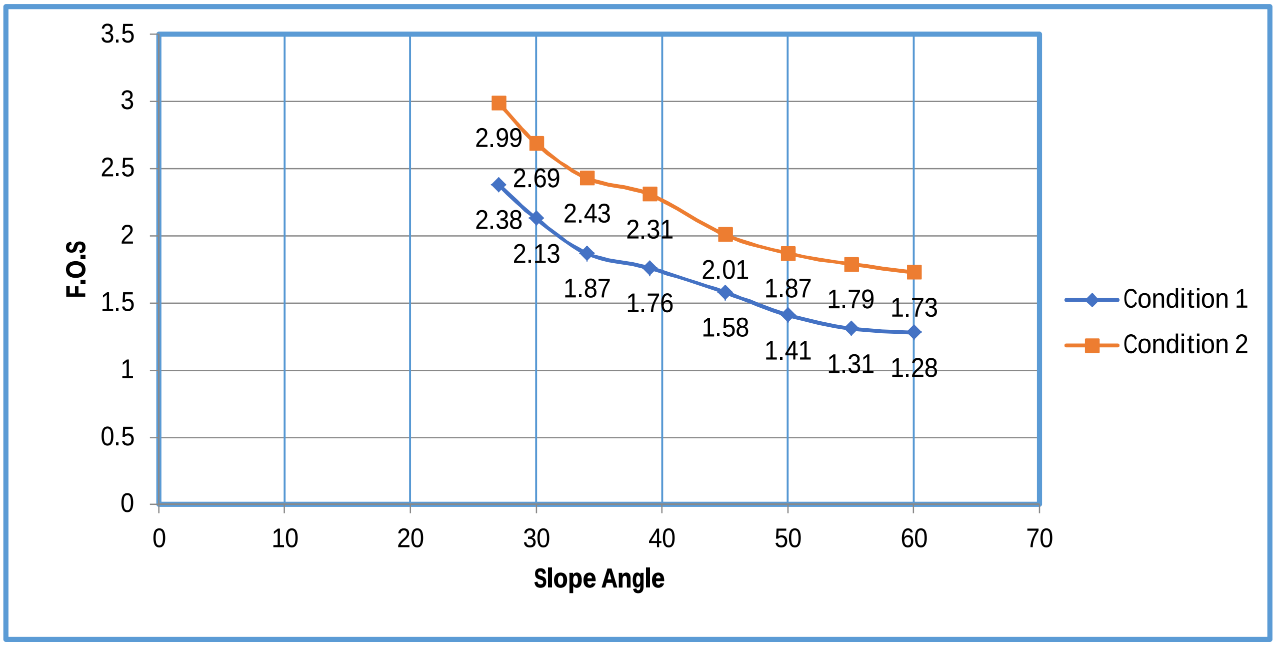
Figure 4 Slope angle vs Factor of safety for double layered soil embankment



1) *Condition 1:* By taking one soil sandy and another soil cohesive in nature.
2) *Condition 2:* By taking both soils cohesive in nature.

V. CONCLUSIONS

A. This study has illustrated that for a particular height of embankment factor of safety against slope stability increases with increase in the flatness of slope.

B. Possible trials made in value angle of internal friction, it has been concluded that as the value of angle of internal friction increases, the value of factors of safety also increases which means more the value of angle of internal friction more is the stability of slope.

C. The main parameters of soil i.e. cohesion also plays important role in the stability analysis. Some trials are made by, considering the cohesion values it has been found that factor of safety against slope stability increases with increase in the value of cohesion.

D. From the present study we can conclude that it is better to use C-ϕ soil rather than ϕ soil as it gives maximum factor of safety as compared to sandy soil.

E. From the analysis results of double layered soil we can conclude that condition 2 (with both soil cohesive) is found satisfactorily better with respect to condition 1 (with one soil cohesive and one soil sandy).

F. By considering condition 2 in the construction of highway embankment. It is found that the increment of 25 to 30% in the factor of safety of condition 1 takes place.

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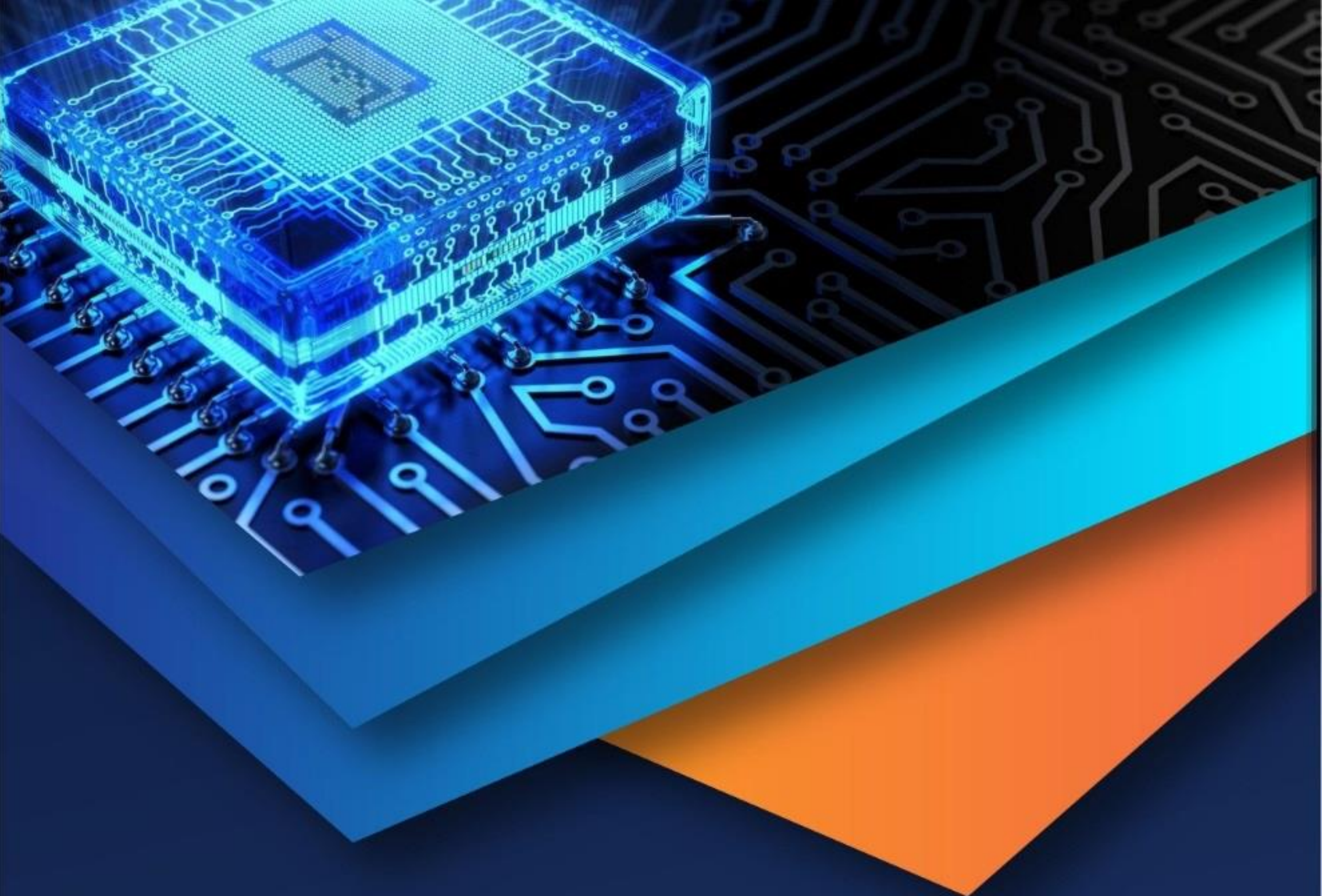

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