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Investigation of Shear Strength Properties of Municipal Solid Waste and Slope Stability Analysis

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Abstract: Municipal Solid Waste (MSW) is composite refuse consisting of various materials with different properties. The characteristics of municipal solid waste play a key role in many aspects of waste disposal facilities and landfills. Leachate resulting from this is hazardous pollutant to the soil and ground water underlying. Leaching of this leachate and heavy metals into the soil leads to the pollution of both soil and subsurface water. Municipal solid waste disposal on land has become one of the challenges in landfill engineering design. The stability of landfill is governed by the physical properties and strength parameters of MSW. In design of landfill, stability analysis are performed using the shear strength parameter of municipal solid waste materials in the form of the cohesion value and the internal friction angle obtained from direct shear and triaxial tests. In this paper results of laboratory investigation of the geotechnical properties of MSW, collected from different dumping sites are presented. The influence of these properties on the stability of the landfill and other issues of MSW in the designing of landfill are discussed.

Keywords: Municipal Solid waste (MSW), Shear strength, Leachate, Geotechnical Characterization, Stability.

I. INTRODUCTION

Investigating the geotechnical properties and behaviour of municipal solid waste (MSW) bodies is challenging due to the variety of material present. It is composite refuse consisting of a mixture of materials with different properties. Municipal solid waste mainly consists of kitchen waste, plastics, paper product, textile, garden waste, construction demolition waste, metals, and wood waste etc. However the composition of MSW varies from region to region and it depends upon lifestyle, demographic features and legislation. Open dumping has been the most accepted practice of solid waste disposal. On an average, 5–6% of the wastes are disposed of by using various composting methods [1]. The scope of waste reduction programs and other eco-friendly methods of waste disposal decreases because of lack of technical infrastructure, political willpower, and awareness among people [2].

Proper management of growing quantities of municipal solid wastes (MSW) has been a major concern of environmental professionals. In spite of recycling and reuse efforts as well as incineration, huge quantities of MSW are still required to be disposed of in engineered landfills. The collection of reliable data regarding generation and characterization of the waste is the key to a successful MSW management. Presently, lack of reliable information and data regarding generation rate, amount, and nature of solid waste creates a hurdle in developing an appropriate waste management plan.

The geotechnical properties of municipal solid waste (MSW) are of vital importance in designing and assessing the performance of landfill and in ensuring safe long-term containment of municipal solid waste so that human health and the environment are not exposed to too much risk. Geotechnical properties of municipal solid waste are difficult to determine because the heterogeneity, wide variation in particle size distribution and time dependent degradation. Geotechnical properties of municipal solid waste are determined through in-situ and laboratory tests and /or back analysis of field performance data [3].

In landfill design and slope stability analysis the characterization of the geotechnical properties of municipal solid waste is necessary as well as other specific physical properties such as composition, unit weight, water and organic contents and permeability are also has prime importance. The water and organic content have a direct effect on the long-term mechanical response of the MSW as they affect the processes of biodegradation [4].

However, knowledge of unit weight, vertical compressibility, shear strength, lateral stiffness, in situ stresses and hydraulic conductivity is fundamental to the assessment of landfill stability and integrity. The safety and stability of the landfills need to be assessed based on data from landfills. In this context characterization of municipal solid waste is important [5].

Most of the landfills are made up of municipal solid waste, the overall stability of the landfill slopes are governed by the strength parameters and physical properties of the municipal solid waste. On the other hand, the composition of the waste, which affects the

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geotechnical behavior of the municipal solid waste, is dependent on a variety of factors such as climate, disposal technology, the culture and habits of the local community. It is therefore essential that the design and stability analysis of landfills in each region be performed based on the local conditions and the geotechnical characteristic of the MSW.

This paper attempts to investigate the factors such as normal stress, shear stress, fiber content, etc. on the geotechnical properties of municipal solid waste materials. By comparing the results of municipal solid waste samples in direct shear test and triaxial test, the effect of the shearing on MSW materials are discussed.

Municipal solid waste collected from four different dumping sites of Satna district were taken for the study the geotechnical properties of municipal solid waste. Considerable work has been made in the laboratory to investigate the parameters like permeability and shear strength etc. This paper shows and analyzes the result of the test performed on the municipal solid waste collected from different dumping sites.

II. MATERIALS AND METHODS

A. Description of the Study Area

To investigate the geotechnical properties of municipal solid waste, four different dumping sites of Satna district namely- near Adarsh Nagar Satna, near Khermai Mandir Satna, Chitrakoot Nagar Panchayat and Maihar Nagar Palika were taken for this study. These selected sites are abbreviated as, Site-1: near Aero Drum, Adarsh Nagar Satna as Station A; Site-2: near Khermai Mandir, Satna as Station B; Site-3: Chitrakoot MP as Station C; Site-4: Maihar as Station D

Figure: 1 Selected four dumping sites namely Station- A, Station- B, Station – C and Station –D respectively.

B. Sampling and Laboratory Testing of Municipal Solid Waste

The Municipal solid waste samples were collected from the randomly from the selected dumping sites. Samples were collected into the separate bags and some relatively small portion of the collected samples were placed in air tight polythene bags for the purpose of measuring natural moisture content. Random sampling was adopted for fair representation of municipal solid waste bottom sediments. The collected samples were subsequently transported to the Geotechnical laboratory for testing. Different geotechnical tests were conducted on these collected samples in accordance with the Indian Standard (I.S.) as well as American Society of Testing and Materials (ASTM).

Shear resistance is a geotechnical parameter of primary concern in describing the properties of MSW. Direct shear tests were conducted to determine the shear strength parameters (cohesion and friction angles) of municipal solid waste. Tests were performed in accordance to ASTM D3080. The samples were compacted in a square shear box of 60 mm x 60 mm. The height of the box is 50 mm. The size of sample was 60 mm in length, 60 mm in width and 25 mm in height. The stress-strain response of the waste are plotted and the cohesion and the friction angle values were obtained. Figure 2 shows schematic diagram of direct shear test cell.

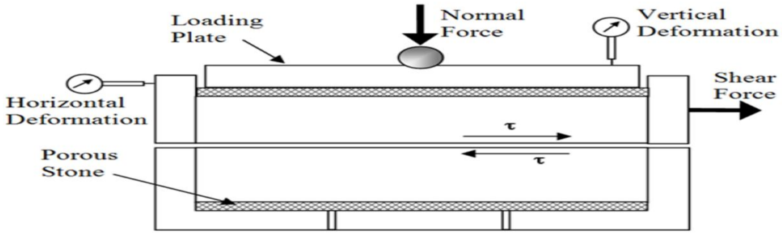

Figure 2 Schematic diagram of direct shear test cell

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A schematic diagram of shear box shows that soil sample is placed in a square box which is split into upper and lower halves. Lower section is fixed and upper section is pushed or pulled horizontally relative to other section; thus forcing the soil sample to shear/fail along the horizontal plane separating two halves. Under a specific Normal force, the Shear force is increased from zero until the sample is fully sheared. The relationship of Normal stress and Shear stress at failure gives the failure envelope of the soil and provide the shear strength parameters (cohesion and internal friction angle).

The slope stability analysis are generally performed to measure the safe and economic design of human-made or natural slopes such as water embankments, mine excavations, landfills, open-pit mining, etc. and the balancing conditions. The calculation of slope stability was performed using slope stability chart given by Taylor and safe bearing capacity of MSW by Terzaghi's lab method. Chart solutions also provide a quick means of checking the results of detailed analysis.

III. RESULT AND DISCUSSION

Direct shear test and Triaxial test conducted for determination of shear strength properties and stability analysis of municipal solid waste.

A. Direct Shear Test

Determination of MSW shear strength properties is difficult and precious due to the inconsistent composition of landfill material, difficulties in sampling and testing, and time-dependent properties. Shear strength of MSW is usually defined using the Coulomb failure criterion as follows

$\tau = c + \sigma \tan\varphi$ …….. (1)

Where τ is the direct shear strength of MSW, c is the cohesion intercept; σ is the total normal stress and φ angle of internal friction.

In the present study the direct shear tests were performed with bulk density 10.30 KN/m^3 and for confining pressures of 50, 100 and 150 kPa. The size of sample was 60 mm in length, 60 mm in width and 25 mm in height. The Shear stress Vs Normal stress response of the waste are plotted for the selected site samples in figure 3.1(a), 3.2(b), 3.3(c) and 3.4(d), and the cohesion and the friction angle values were obtained. The results of the laboratory tests of selected sites, the shear strength parameters are summarized in Figure 3 and Table-1.

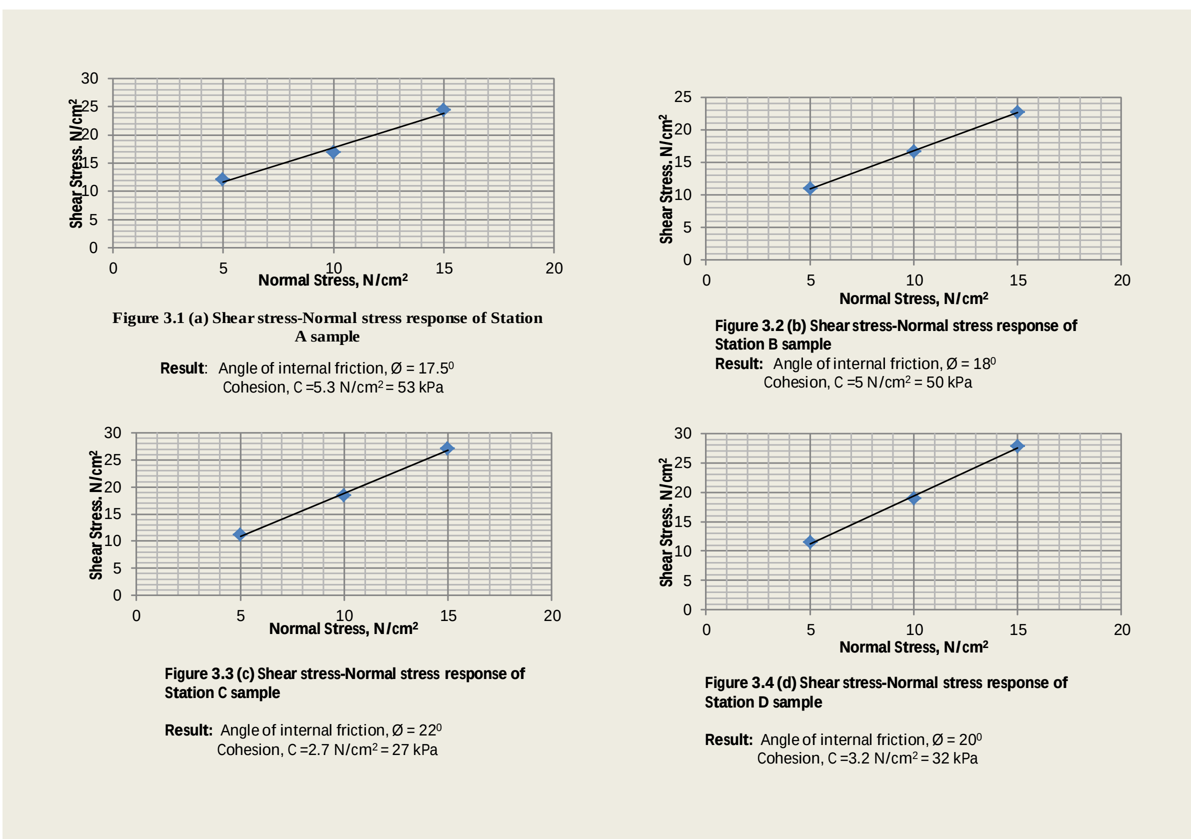

Figure 3.1 (a) Shear stress-Normal stress response of Station A sample

Result: Angle of internal friction, Ø = 17.5⁰ Cohesion, C =5.3 N/cm² = 53 kPa

Figure 3.2 (b) Shear stress-Normal stress response of Station B sample

Result: Angle of internal friction, Ø = 18⁰ Cohesion, C =5 N/cm² = 50 kPa

Figure 3.3 (c) Shear stress-Normal stress response of Station C sample

Result: Angle of internal friction, Ø = 22⁰ Cohesion, C =2.7 N/cm² = 27 kPa

Figure 3.4 (d) Shear stress-Normal stress response of Station D sample

Result: Angle of internal friction, Ø = 20⁰ Cohesion, C =3.2 N/cm² = 32 kPa

Figure 3 Shear Stress – Normal Stress response of selected site samples

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Table-1 Shear Strength parameters of MSW site samples (Cohesion and friction angle)

Sl. No	Site Name	Cohesion Value, C	Angle of Friction , Ø
1	Station -A	53 kPa	17.5^0
2	Station- B	50 kPa	18^0
3	Station- C	27 kPa	22^0
4	Station -D	32 kPa	20^0

In present study of municipal solid waste (MSW) sites sample, the cohesion (C) values vary from 27 kPa to 53 kPa and friction angles (Ø) from 17.5^0 to 22^0.

B. Triaxial Test

Unconsolidated Undrained tests were performed in the laboratory for sample size 50 mm diameter and100 mm heights. The sample was statically compacted with a density of 10.3 kN/m^3 and 30% water content. The observation and calculation for shear strength parameters are done for all the selected sites samples.

The Shear stress Vs Normal stress response of the waste are plotted as Mohr Circle for the selected site samples shown in figure 4.1(a), 4.2(b), 4.3(c) and 4.4(d). Results of the laboratory tests of unconsolidated undrained test for all the site samples are summarized in the Table-2.

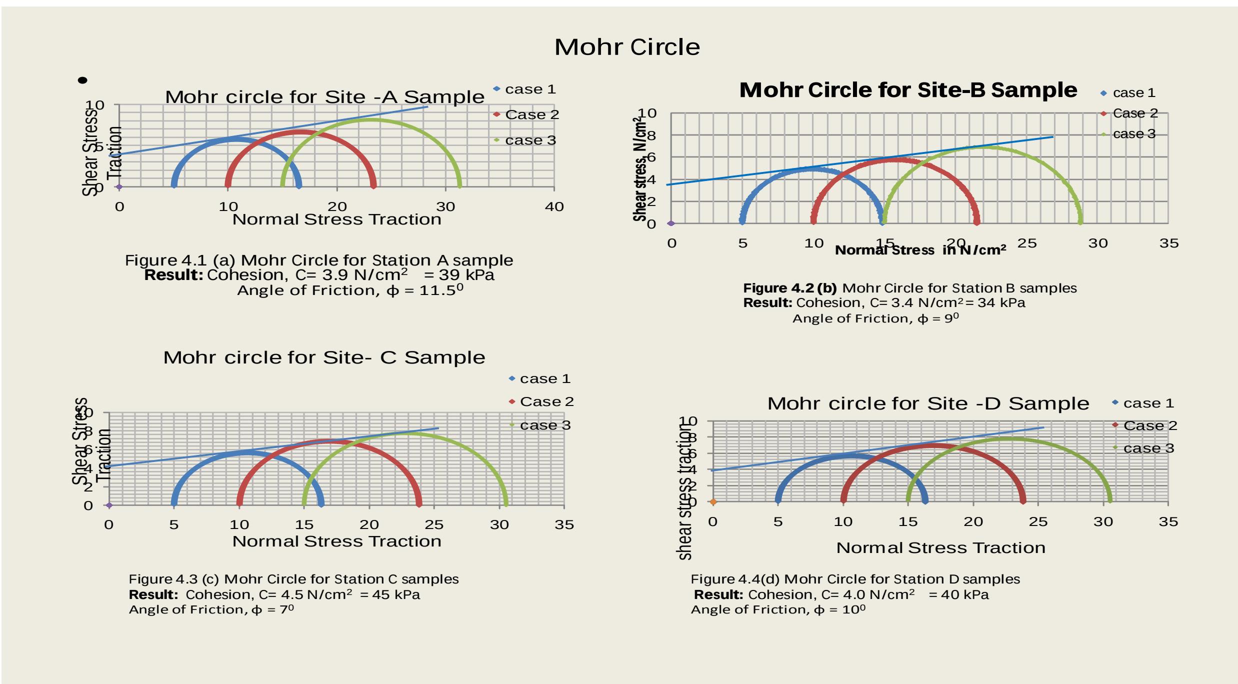

Figure- 4 Shear stress Vs Normal stress response of the waste for the selected site samples

Table- 2 Triaxial test results parameters of site samples (Cohesion and friction angle values)

Sl. No	Site Name	Cohesion Value, C	Angle of Friction , Ø
1	Station- A	39 kPa	11.5^0
2	Station -B	34 kPa	9^0
3	Station -C	46 kPa	7^0
4	Station- D	40 kPa	10^0

In present study of municipal solid waste sites sample the cohesion **(C)** values vary from 34 kPa to 46 kPa and friction angles **(Ø)** vary from 7^0 to 11.5^0

C. Stability Analysis

As the Municipal Solid Waste is assumed to behave as soil and has characteristics similar to soil such as multi grained, partially saturated, variable soil size structured. The behavior of MSW is assumed to be frictional in nature and is governed by Mohr-Coulomb criteria. Geotechnical properties of municipal solid waste are investigated through laboratory testing.

One of the structural failures that can occur in a landfill is due to incorrect geometrical design of the slopes due to low safety factor (SF). Geotechnical and physical properties of the waste to be deposited must be known to calculate the SF of the slope in a landfill. Density depends directly on the composition, moisture and the degree of compaction and is one of the needed parameters to determine the stability of a slope. The other required parameters are the cohesion (C) and the angle of friction (Ø).

1) *Safe angle of slope for landfills:* For calculation of safe angle of slope of landfill sites, using Talyor's stability number few assumptions / considerations are made. Considering the height of landfills as 20 M and factor of safety F_c as 3. Factor of safety is taken high because the unit weight of municipal solid waste was found around 8 kN/m^3. Taylor's Stability Number S_n is given by the equation:

$$S_n = C / F_c \gamma H \quad \text{……………………. (2)}$$

For a known stability number and friction angle the safe angle of slope is calculated by using the Taylor's Chart.

The result shows that safe angle of slope value varies from 27^0 to 55^0 for different values of cohesion and friction angles for selected dump sites, considering height of landfill 20 M & factor of safety value 3.

2) *Safe bearing capacity:* Calculation of safe bearing capacity of all four landfill locations using Terzaghi's bearing capacity theory few assumptions / considerations are made same as in safe angle of calculations. Considering the height of landfills as 20M and factor of safety F_c as 3. Using the equilibrium analysis, Terzaghi expressed the ultimate bearing capacity in the form as given below (for strip foundation):

$$q_u = c\,N_c + \gamma\,D_f\,N_q + 1/2\,\gamma\,B\,N_\gamma \quad \text{………………………………. (3)}$$

Where, **C** = cohesion of soil, γ = unit weight of soil, D_f = Depth

Nc, Nq, Nγ = bearing capacity factors that are non-dimensional and are only functions of the soil friction angle, ϕ.

For a given value of friction angle, the bearing capacity factors are found from Tarzaghi's bearing capacity factors chart. Safe bearing capacity of selected dump sites are calculated by using equation (3), for given value of friction angles.

The results shows that the safe bearing capacity value varies from 118.54 kN/m^2 to 301.16 kN/m^2 for different values of cohesion and friction angles for selected dump sites, considering height of landfill 20 M & factor of safety value 3**.**

IV. CONCLUSION

Based on the laboratory investigation and above results in present study of municipal solid waste sites sample, the cohesion **(C**) values vary from 27 kPa to 53 kPa and friction angles (Ø) from 7^0 to 22^0.

The result shows that safe angle of slope value varies from 27^0 to 55^0 for different values of cohesion and friction angles for selected dump sites, considering height of landfill 20 M & factor of safety value 3. The results shows that the safe bearing capacity value varies from 118.54 kN/m^2 to 301.16 kN/m^2 for different values of cohesion and friction angles for selected dump sites, considering height of landfill 20 M & factor of safety value 3**.**

From above results and discussion the work presented in this paper has enhanced the fundamental understanding of the geotechnical behaviour of municipal solid waste. Municipal solid waste usually consists of food, paper, and plastics as a principal constituent and variation in the composition of waste materials can significantly affect the waste response in different ways.

Consequently the strength properties of municipal solid waste evaluated with different waste composition may provide additional insight for landfills where the composition of waste may be known and can help to make better design decisions. These findings will help in guiding geotechnical engineers when designing and constructing foundations for buildings and other related structures on these types of soils.

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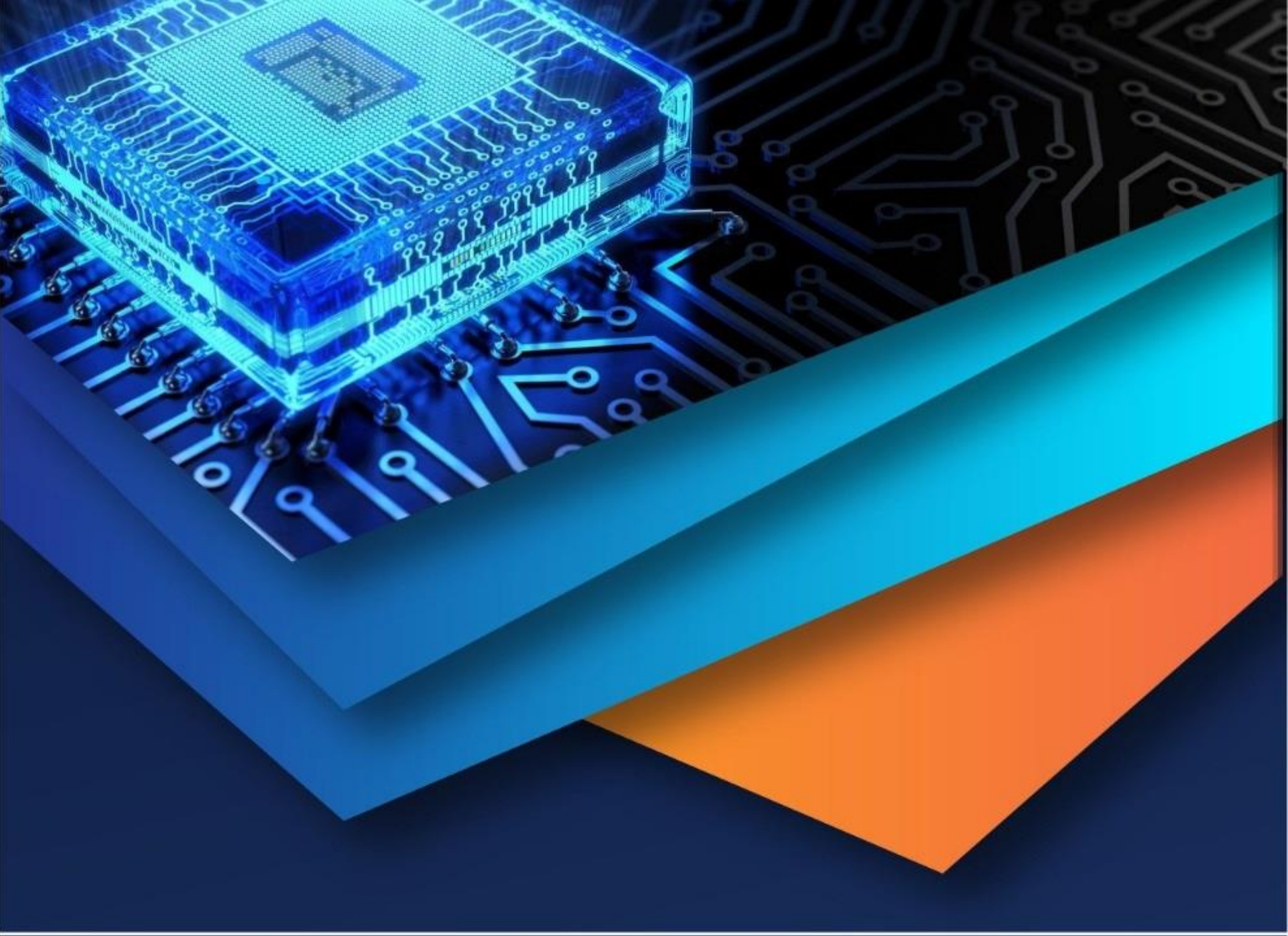

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