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Study of Suitable Foundations for Black Cotton Soil

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Abstract: In Civil Engineering aspects Black Cotton Soil is giving hazardous problems to engineers. With the rapid development in Soil improvement, construction technique and social need various constructions of structure are taking place. The possibility of good construction sites to build structures on Black Cotton Soils is difficult due to their poor strength and deformation characteristics. This study discussed Black Cotton Soil properties, effect of Black Cotton Soil on structures and covers the guidelines to construct the structure in Black Cotton Soil.
Keywords: Black Cotton Soil, Foundation, Suitability.

I. INTRODUCTION

A. Aim
To study the properties of Black Cotton Soil and suggest suitable foundation.

B. Objective
The study aims at removing the possibility of failure of foundation by tilting, overturning, uprooting and sliding due to intensity imposed on soil by foundation being in excess of the ultimate capacity of the soil. The purpose to carry the above mentioned project is:
1) To study the physical properties of Black Cotton Soil.
2) To suggest a proper foundation for the Black Cotton Soil.

C. Need
Superstructure loads are transmitted to the underlying soil strata through a suitably designed foundation. Therefore, the foundation of a structure is considered the most crucial structural element in a building. Black cotton soil has a tendency to swell and shrink excessively. This alternate process of swelling and shrinking results in the differential settlement of the foundation which in turn causes cracks in building. Hence, it is very necessary to analyze the safety and stability of the foundation

II. LITERATURE REVIEW
U.G.Fulzele et al. (1), studied the problems related with black cotton soil, their remedies, precautions and discussed the guidelines to construct the structures in black cotton soil. Various tests were conducted on different types of foundation in black cotton soil and recommendations are given according to the results.
Vinayak Kaushal et al.(2) studied the Black cotton soils from Indrasagar Rockfill Dam, Polavaram, Andhra Pradesh (India) from a depth of 1m, 1.2 m and 1.5 meters. Physical and geotechnical properties of the soil samples were studied in the laboratory. The tests conducted were grain size analysis, specific gravity, Atterberg's limits, standard Proctor compaction, consolidation and direct shear test. Results as obtained were compared with the Indian standard code. Further, relationships of plasticity index with liquid Limit and optimum moisture content, compression index with liquid limit, optimum moisture content and plasticity index, angle of internal friction with plasticity index were also derived. The test results have shown that increase in the clay content in the black cotton soil attributes an increase in the plasticity index.
A.K. Singhai et al. (3), tried to find out type of foundation best suitable for different soil condition of the area of Jabalpur for the construction of multistoried building with technical as well as economical parameters.
V. Suneetha and Dr. D.S.V. Prasad (4), the main objective of their study was to design a suitable and feasible foundation for the black cotton soil for a G+2 structure foundation system, it is found that under-reamed piles provide an ideal solution to foundation in black cotton soil or other similar types of expansive soil.

Hadj Brahim Mounia et al. (5), analyzed the effect of number of floors of a building, founded on isolated footing on the stability of the slope using the computer code finite element. The isolated footings of a building in this case were anchored in soil so that levels of successive isolated footing realize a maximum slope of base of three for two heights, which connects the edges of the nearest footings.

Prof. Nagrajbacha et al. (6), investigated the behaviour of Black Cotton Soils, essentially containing montmorillonites as principal clay mineral and having different clay contents/ mineralogical contents, in the presence of inorganic chemical fluids such pore fluids.

Piotr Pezowicz (7), investigated shearing resistance and compressibility of fine-grained cohesive soil in relation to the increasing moisture content. The analysis of two series of samples, using soil paste for the consistency index of 0.9 and 0.4–0.3 was carried out. The results imply that the increasing moisture content causes a decrease in the angle of shearing resistance and cohesion and is also reflected in the higher compressibility of the soil. It was observed that regardless of the soil consistency, the angle of shearing resistance decreases and the cohesion value and the oedometric modulus of primary (consolidation) and secondary compressibility grows with the increase in the clay.

Chaitanya Mycherla (8), studied a 2cellars+G+14 building at Yen dada, Vishakhapatnam, India. The study involves the construction of substructure of building, which includes site selection, soil test, leveling, earth work, foundation, retaining wall, columns, beams and slab.

George Geoffrey Meyerhof (9), summarizes the results of recent research on the bearing capacity of spread foundation of various shapes under a central vertical load and outlines the effect of foundation depth, eccentricity and inclination of the load. Simple formulae have been derived for use in practice and their application to the design of rigid and flexible foundations is briefly indicated.

Pavan Parashram Belgaonkar et al. (10), studied the effect of various parameters on affecting the settlement of the foundation. A 4-storied is considered for settlement. For settlement calculation, three types of soil were considered i.e. Dense Sand, Stiff clay and Gravely soils. The parameters were varied for these soil types and the settlement for depths lesser than minimum depth of foundation and greater than minimum depth of foundation are calculated. Based on these analyses, the effect of Elastic Modulus of soil, Shape of foundation and depth of foundation in all three soils were observed.

III. DETAILED STUDY

A. What is Black Cotton Soil ?

Expansive soils, most popularly known as Black Cotton Soils in India, are amongst the most problematic soils from Civil Engineering point of view. Of the various factors that affect the swelling behaviour of these soils, the basic mineralogical composition is very important. Most expansive soils are rich in mineral montmorillonite and a few in illite. The degree of expansion being more in the case of former, soil suction is another quality that can be used to characterize a soil's affinity for water on its volume change behaviour.

Black Cotton Soil is heavy clay soil, varying from clay to loam; it is generally light to dark grey in colour, as it is formed from lava basaltic rock. Cotton grows in this kind of soil. The soil prevails generally in central and southern part of India.

The most important characteristic of the soil is, when dry, it shrinks and is hard like stone and has very high bearing capacity. Large cracks are formed in the bulk of the soil. The whole area splits up and cracks up to 150mm wide are formed up to a depth of 3.0 to 3.5 meter. But when the soil is moist, it expands, becomes very soft and loses its bearing capacity.

Due to its expansive character, it increases in volume to the extent of 20% to 30% of original volume and exerts pressure. The upward pressure exerted becomes so high that it tends to lift the foundation upwards. This reverse pressure in the foundation causes cracks in the wall above. The cracks are narrow at the bottom and are wider as they go up. Various types of damages can occur in the building due to uplift forces and settlement caused by the expansive soils, such as

1) Diagonal and vertical cracks in smaller direction of slab.
2) Vertical cracks in internal and external walls.
3) Horizontal cracks in slab as cantilever action is created in slab.
4) Detachment of slab in outer walls towards outside.
5) Bending action in outer walls towards outside.
6) Detachment of plinth protection.
7) Heave and settlement in floors.

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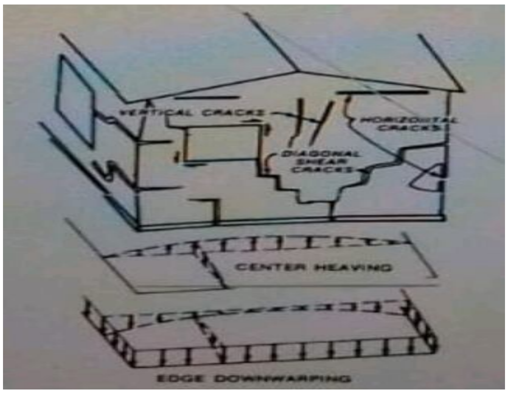

Fig.1 Damages caused due to Black Cotton Soil

The unusual characteristics of the soil make it difficult to construct foundation in such soil. Special method of construction of foundation is needed in such soil.

B. Properties of Black Cotton Soil

Black cotton soil (BC soil) is a highly clayey soil. The black colour in Black cotton soil (BC soil) is due to the presence of titanium oxide in small concentration. The Black cotton soil (BC soil) has a high percentage of clay, which is predominantly montmorillonite in structure and black or blackish grey in colour. Black cotton soil (BC soil) has very low bearing capacity and high swelling and shrinkage characteristics. Due to its peculiar characteristics, it forms a very poor foundation material for construction. The construction of foundation for structure on black cotton soils poses challenge to civil engineers.

C. Physical Properties

Properties	Black Cotton Soil
Colour	Dark grey to black
Recommended values as per IS 1498 : 1970	
Specific Gravity	2.6 – 2.8
Grain Size Distribution	
Fine sand (%)	7
Silt (%)	17
Clay (%)	76
Atterberg's Limit	
Liquid Limit (%)	30 – 50
Plastic Limit (%)	Less than or equal to 40
Compaction Characteristics	
Maximum Dry Density [kN/m³]	1.92
Optimum Moisture Content (%)	upto 21%
Unconfined Compressive Strength [kN/m²]	145.5
California Bearing Ratio	2 - 4
Angle of internal friction	25 – 35 °
Cohesion	12 – 24 kN/m²

D. Engineering Properties

The prominent engineering properties of the Black Cotton Soils which are of primary importance from practical point of view and which are most often necessary for a civil engineer to understand are:

1) *Volume Change Behaviour Of Black Cotton Soils:* Volume change behaviour of these soils are important because of their consequences on the deformation criterion of earth structures and other structures founded on these soils. Most often, these black cotton soils when wetted because of heavy rains or some other means, the volume change takes place; which is in fact a consequence of swelling. The black cotton soils having great affinity towards moisture, exhibit high swelling and shrinkage behaviour, which is generally known as swelling potential or degree of expansiveness ; on which the vertical movement or the

settlement of the structure constructed on such soils depends upon. Several cases of foundation failures are reported particularly due to increased volume changes in foundation soil. The swelling effect in the black cotton soils results from additional embedding of water/solution molecules into the soil matrix, remarkably into the inter-layers of expansive minerals. The important factors that influence the swelling behaviour of soils include type and amount of clay minerals, soil structure, dry density, initial water content, compaction method, thermal conditions, and electrolyte concentration in the pore water etc.

2) *Strength Characteristics:* In general, the strength of a material means its capacity to resist deformation against compression or tension; which are termed as its compressive strength or tensile strength respectively. However in most of the geotechnical problems in civil engineering (such as foundations of structures, earthen embankments etc.), the soil mass has to withstand shearing stresses, which in nature are quite unlike the compressive or tensile stresses. The stability of a soil mass is thus its resistance to deformation under stress application. The shearing stresses tend to displace a part of soil mass relative to the rest of the soil mass. The capacity of the soil to resist the shearing stresses represents its strength; which is categorically termed as the 'shear strength of the soil'. Thus, by the strength characteristics of a soil, it is meant the shear strength characteristics. The shear strength of a soil is its most important engineering property, which in fact enables the soil mass to keep its equilibrium under any loading situation that produces shearing stresses.

A soil derives its shearing strength from the following:

a) Resistance due to interlocking of soil particles

b) Frictional resistance between the individual soil grains which may be a sliding, friction, rolling friction or both.

c) Adhesion between the soil particles which is commonly known as cohesion (c).

Highly plastic soils such as Black Cotton Soils, derive their strength from the third source i.e. cohesion, for their shear strength, even though they possess a comparatively small frictional resistance. The shear strength of the black cotton soils is also influenced by the amount and type of clay minerals present and also by the amount of cementitious materials. It is noted that the strength of clayey soils reduces with the increasing content of montmorillonite in the clay fraction. The strength gets enhanced with increase of presence of cementing agents, especially calcite and pyrite. The shear strength of a soil cannot be tabulated in codes of practice, since a soil can significantly exhibit different shear strengths under different field conditions.

3) *Compaction Characteristics:* Compaction is a process by which the soil particles are artificially rearranged and packed together into a closer state of contact by mechanical means in order to decrease the porosity (or voids ratio) of the soil and thus increase density. It has long been recognized, first empirically and then scientifically that compaction changes the physical properties of soils; thereby improving its engineering behaviour . The basic purpose of compaction is therefore to improve the engineering properties of the soil mass; particularly in case when the soil is required to be used for the construction works. Compaction of a soil generally increases its shear strength, decreases its compressibility and permeability. Following are the major effects of compaction on the black cotton soils:

a) Compaction increases the dry density of the soil, thus increasing its shear strength and bearing capacity.

b) Compaction reduces the compressibility of soil, thereby decreasing the tendency for settlement of structures founded on these soils.

Compaction of a soil is measured in terms of the dry density of the soil, which is the weight of the soil solids per unit volume of the soil bulk. It is calculated using the wet or bulk density and the water content of the soil by means of the following relation:

$$\gamma_d = \frac{\gamma_b}{1+w}$$

Where

γ_d = dry density of the soil

γ_b = wet or bulk density of the soil

w = water content expressed as fraction

Compaction increases the strength characteristics of soils, which enhances the bearing capacity of foundations constructed over them. It also decreases the amount of undesirable settlement of structures and increases the stability of slopes of embankments.

E. Seasonal Variation Parameters In Black Cotton Soil

Depending upon the initial water content of the soil and the quantity of water imbibed, the Black Cotton Soils exhibit the change in their volume when water gets access into them. The moisture variation in these soils may result from seasonal climatic changes, changed surface conditions and extraneous influences such as supply of moisture due to poor drainage, broken drains, transpiration (drying effect) etc. The swelling characteristics of these soils result in heaving, distortion, cracking and breaking up of pavements,

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buildings, channels, buried conduits and reservoir linings. The shrinking characteristics of the black cotton soils due to prolonged drought can cause severe settlements which may be detrimental to the structures founded on them. In road pavements, extensive cracking may occur. These shrinkage cracks increase permeability of the impervious core of swelling black cotton soils and this may cause seepage problems in water reservoirs.

The range of variation of engineering property parameters of the Black Cotton Soil are given in Table below:

Property parameters	Variation range	Units
Free swell index	33 – 156	%
Differential free swell	27 – 119	%
Optimum moisture content	upto 21	%
Maximum dry density	1.60 – 1.92	gm/cm³
Unconfined compressive strength	70 – 137	kN/m²
California bearing ratio	1.08 – 4.30	%

A study of variation ranges of the free swell index and the differential free swell of the soils indicates that these soils exhibit high degree of expansiveness. The range of values of unconfined compressive strength hints at low to moderate shear strength of these soils. The optimum moisture content and maximum dry density value ranges highlights the fact that these soils are less suitable for the construction of earthen embankments, earthen dams and other similar structures. The low range of California bearing ratio values indicate the low suitability of these soils for the construction of roads.

F. Foundation in Black Cotton Soil

Construction on Black Cotton Soil, commonly known as shrinkable soil has always been a difficult problem for the engineers. Inspite of many precautions, the structure built on Black Cotton Soil cracks terribly without any warning. In India, about 16% of the land comprises of Black Cotton Soil and this type of soil is found in many other countries of the world.

G. Causes of Foundation Damage due to Black Cotton Soil

Expansive soils in many parts of the India pose a significant hazard to the foundations for buildings. Swelling clays from derived soils can exert uplift pressures, which can do considerable damages to structures.

H. Foundation Damage

The most obvious way in which expansive soils can damage the foundations is by uplift as they expand/swell with the moisture increase. Swelling soils lift up and crack lightly loaded, continuous strip footing and frequently cause distress in floor slabs.

Because of the different loads on different portions on structure's foundation, the resultant uplift will vary in different areas. As shown in fig., the exterior corners of a uniformly loaded rectangular slab foundation will only exert about one-fourth of the normal pressure on a swelling soil of that exerted at the central portion of the slab. As a result the corners tend to be lifted up relative to the central portion. This phenomenon can be exacerbated by the moisture differentials within soils at the edge of the slab. Such differential movement of the foundation can also cause distress in the framing of the structures.

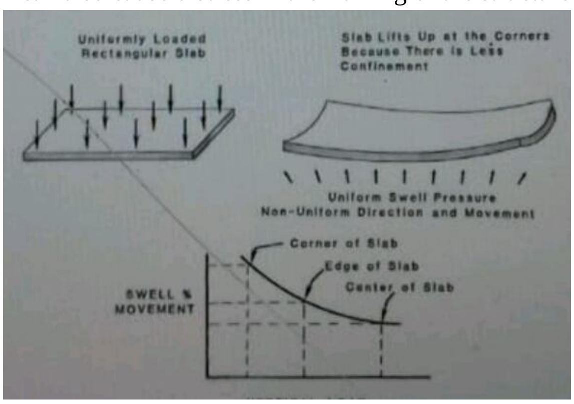

Fig.2 Lifting up of corners of uniformly loaded rectangular slab due to less confinement

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I. Principles Of Construction Of Foundation In Black Cotton Soil

1) Foundation load is limited to 5.0 tonnes/sqm, if there is accessibility of water to the foundation, otherwise load may be upto 10 tonnes/sqm.
2) Foundation excavation is extended beyond the depth of cracks. The minimum depth of foundation should be at least 1.5m.
3) Foundation trench is made wider than required and the extra width is filled with granular materials to prevent intimate contact of black cotton soil with the foundation structure.
4) If the thickness of black cotton soil strata is not more than 1,200mm, it is advisable to remove it completely and place the foundation below that depth.
5) In cases of important buildings, R.C.C. raft foundation is recommended.

J. Footings suggested for Black Cotton Soil

As far as Black Cotton Soil is concerned for single storey or double storied buildings, soil stabilization will be useful. But for multi-storied, or high-rise or super high-rise buildings, the mat or raft foundations are useful.
Following types of footing are mostly used to construct building/house in the Black Cotton Soil depending upon the soil conditions and loads from the structure.

K. Spread Footings and Wall Footings on Black Cotton Soil

Spread footings and wall footings are used where a layer of good soil (soil which is capable of supporting the load of the building or soil which has the sufficient load bearing capacity) is within 2m to 3m (6 to 10 feet) from the natural ground surface. Spread footings and wall footings should not be used where the high flow of the groundwater is found within the depth of foundation as it may result in scouring. However, the soil bearing capacity must be adequate to support the weight of the structure.

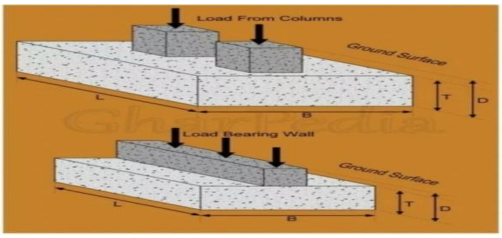

Fig.3 Spread Footing and Wall Footing

L. Under Reamed Piles on Black Cotton Soil

An under reamed pile is a pile of shallow depth (1 to 6m) having one or more bulb at its lower end. If this bulb is taken or provided at a level lower than the critical depth of moisture movement in Black Cotton Soils, the foundation will be anchored to the ground and it would not move with movement (shrinkage and swelling) of the soil. Hence when the ground has Black Cotton Soil up to 1 to 6m, the under reamed pile foundation is best suitable for low rise buildings. It is safest and economical option to construct the foundation in Black Cotton Soil. In this type of foundation, the building or a house is anchored to the ground at the depth where the ground movement due to changes in moisture content is negligible. If the water-table is high, bentonite slurry is used to retain the sides of the bore-hole against collapse. Based on research carried out at Central Building Research Institute Roorkee and elsewhere, it is found that under-reamed piles provide an ideal solution to foundations in Black Cotton Soil or other similar types of expansive soil.

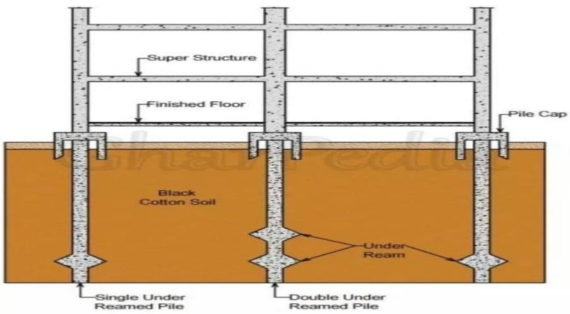

Fig.4 Under reamed Pile Footing

M. Mat Foundation on Black Cotton Soil

The mat foundation is suitable for Black Cotton Soil whose bearing capacity is less for suitability of spread footings and wall footings. It is also recommended and or economical when the area of footing becomes greater than 50% area of the building. This is generally recommended for high rise buildings. For low rise building, it would be very costly. Mat foundation should not be used if high groundwater table is found within the depth of foundation, as it results in scour and liquefaction may occur.

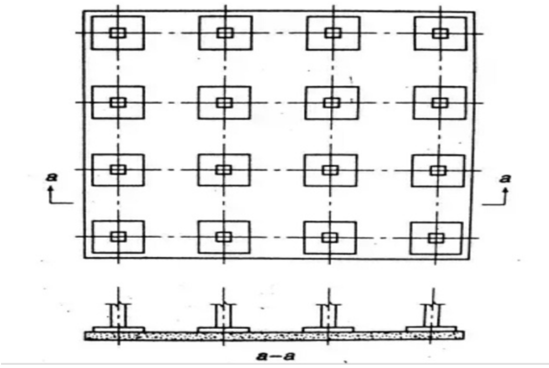

Fig.5 Mat or Raft Foundation

N. Pile Foundation in Black Cotton Soil

The pile foundation is used to transfer the heavy loads from the structure to hard rock strata which is much deep below the ground level and where shallow foundations or mat foundation is not feasible due to weak or expansive soil in upper layer. The pile foundation also prevents uplift of building due to lateral loads such as earthquake and wind forces. Generally, the depth of hard rock strata may be 5m to 50m (15feet to 150feet) deep from the natural ground surface, depending upon local topography and geology. The pile foundation resists the loads from structure by skin friction and by end bearing. Uses of pile foundations also prevent settlements of foundations.

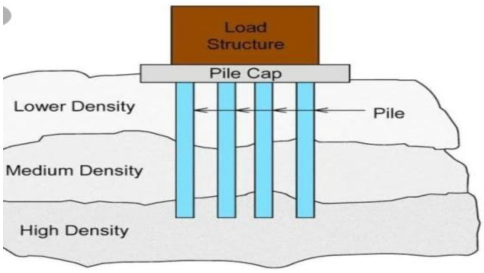

Fig.6 Pile Foundation

O. Drilled Shaft Piles in Black Cotton Soil

Drilled shafts can be used for deep foundations of high rise building where the depth of hard firm strata below the ground is 10m to 100m (25 feet to 300 feet). Drilled shaft foundations are not suitable when deep deposits of soft clays and loose water bearing granular soils exists. It is also not suitable where formations are difficult to stabilize, i.e. soil made up of boulders and artesian aquifer exist.

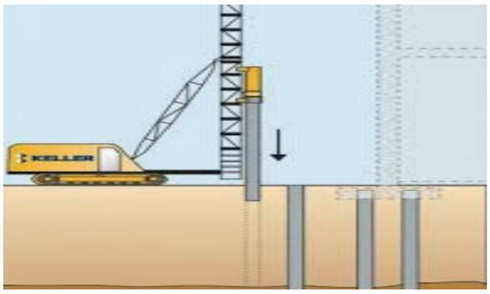

Fig.7 Drilled Shaft Piles

IV. CONCLUSION

From above study, it can be concluded that: due to swelling and shrinking of Black Cotton Soil, it becomes very poor foundation material, especially for Shallow Foundations. The suitability of various foundations studied are:

Spread footings and wall footings can be used where a soil with sufficient load bearing capacity is within 2m to 3m (6 to 10 feet) from the natural ground surface.

Under reamed pile foundation is best suitable for low rise buildings upto 1m to 6m. It is safest and economical option to construct the foundation in Black Cotton Soil.

The mat foundation is suitable for Black Cotton Soil whose bearing capacity is less for suitability of spread footings and wall footings. It is also recommended and or economical when the area of footing becomes greater than 50% area of the building.

Pile foundations can be used for depth of hard rock strata from 5m to 50m (15feet to 150feet) deep from the natural ground.

Drilled shafts can be used for deep foundations of high rise building where the depth of hard firm strata below the ground is 10m to 100m (25 in college.feet to 300 feet). Drilled shaft foundations are not suitable when deep deposits of soft clays and loose water bearing granular soils exists.

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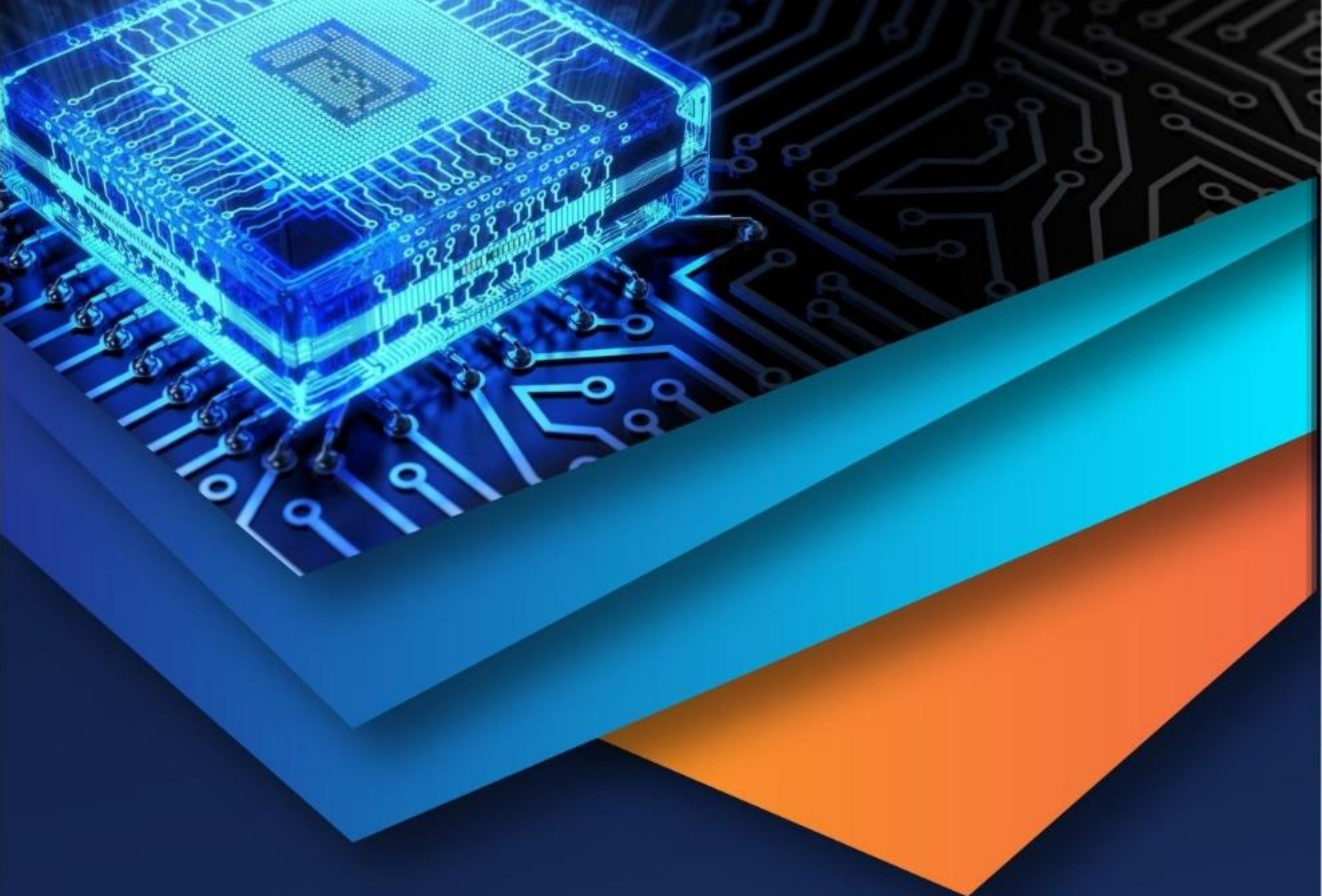

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