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# Stabilization of Black Cotton Soil Using RBI Grade 81 and Sodium Silicate

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***Abstract:*** ***Nearly 51.8 million hectares of land area in India is covered with expansive soils (mainly Black Cotton soil). The property of the expansive soils, in general, is that they are very hard when in dry state, but they lose all of their strength when in wet state. In light of this property of expansive soils, these soils pose problems worldwide that serve as challenge to overcome for the Geotechnical Engineers. One of the most important aspects for construction purpose is soil stabilization, which is used widely in foundation and road pavement constructions; this is because such a stabilization regime improves engineering properties of the soil, such as volume stability, strength and durability. In this process, removal or replacing of the problematic soil is done; replacement is done by a better quality material, or the soil is treated with additives. In the present study, RBI Grade 81 obtained from Alchemist Touchnology Limited, Gurgaon, Haryana and Sodium Silicate solution 5mol/Liter obtained from Organ Refractories, Khammam, Telangana are used for the stabilization of black cotton soil. These additives are added in various proportions***

***1) RBI Grade 81 i.e., 2%, 4% and 6%***
***2) Sodium silicate solution 5mol/Liter i.e., 3%, 4.5% and 6%.***

***The Plasticity Index (PI) of clay - RBI mixes show a decrease in value with increasing RBI Grade 81 content and clay - Sodium Silicate mixes also show a decrease in value with increasing Sodium silicate content. The Unconfined compressive strength (UCS) of clay – RBI mixes show an increase in value with increasing RBI Grade 81 content and clay – Sodium Silicate mixes also show an increase in value with increasing Sodium silicate content. Tested under soaked conditions for 96 hours, the CBR values of clay - RBI Grade 81 show an increase in value with increasing RBI Grade 81 content. However for clay – Sodium Silicate mixes the CBR value decreases with increasing Sodium Silicate content. Analysis of the results exposes the potential of RBI Grade 81 and Sodium silicate both as additives and they could be used for improving the engineering properties of Black cotton soil.***

## I. INTRODUCTION

### A. *Expansive* soil

Expansive soils, which are also called as swell-shrink soils, have the tendency to shrink and swell with variation in moisture content. As a result of this volume variation in the soil, significant distress occurs in the soil, which is subsequently followed by damage to the overlying structures. During periods of greater moisture, like monsoons, these soils imbibe the water, and swell; subsequently, they become soft and their water holding capacity diminishes. As opposed to this, in drier seasons, like summers, these soils lose the moisture held in them due to evaporation, and shrinks. Generally found in semi-arid and arid regions of the globe, these type of soils are regarded as potential natural hazard – if not treated, these can cause extensive damage to the structures built upon them, as well causing loss in human life. Tallied in billions of dollars annually worldwide, these soils have caused extensive damage to civil engineering structures. Consisting of high percentage of clay sized particles, the color of this soil varies from black to chestnut brown. 20% of the total land area, on an average, of this country is roofed by expansive soils. These soils are suitable for dry farming and for the growth of crops like cotton, rice, jowar, wheat, cereal, tobacco, sugarcane, oilseeds, citrus fruits and vegetables; the reason behind it is owed to the moisture retentive capacity of expansive soils, which is high.

In West Godavari region, black cotton soils are found predominant. An experimental investigation is carried out to improve the performance of this soil by using chemical admixtures of RBI Grade 81 and Sodium silicate. Atterberg's limits, Proctor's compaction, Unconfined Compressive Strength and soaked California Bearing Ratio tests were carried out on the samples prepared. Expansive soil for the work was collected from Industrial Estate of Bhimavaram town.

 

As this area was proposed for industrial development, the soil in the area is needed to be tested. Unconfined Compressive Strength and soaked California Bearing Ratio values aredetermined with the soil samples prepared.

The results of the variations tests we carried out on this soil with RBI Grade 81 and Sodium Silicate will help the Bhimavaram municipal corporation at the time of construction in the industrial area. RBI Grade 81 RBI Grade 81 is an odorless beige powder that is composed of a number of naturally occurring compounds. The $P^H$ of saturated paste is 12.5. It improves the structural properties of a wide range of soils. It is particularly effective with silty-clayey soil with low geo-mechanical qualities. RBI Grade 81 works by hydration reaction. Pore space is filled by a crystalline growth. Through the addition of low dosages of RBI Grade 81, the volume stability of the soil is increased significantly. The reaction of RBI Grade 81 with soil particles produces as an inter-particle matrix that binds soil particles together into a rigid mass. This binding of the soil particle, through both chemical bonds and frictional forces, serves to limit the pore volume of the created rigid stabilized soil system.

RBI Grade 81 is insoluble in water, non UV degradable, inert and chemically stable. It forms a dust free surface and is simple to apply and hardens fast. It is durable and permanent. It is environmental friendly and aesthetically pleasing. Strength of silt treated with RBI Grade 81 increases with age. RBI Grade 81 converts clay irreversibly into cementious calcium silicate and aluminum hydrates. RBI Grade 81 creates a volume stable layer with very small capillaryspaces. Application of RBI Grade 81 was carried out by researchers in the past and the composition of RBI Grade 81 is summarized below.

*B. Composition of RBI Grade 81*

| S.no | Chemical composition | | | Physical significance | |
|---|---|---|---|---|---|
| 1 | Ca | CaO | 52-56 | Odor | Odorless |
| | Si | $SiO_2$ | 15-19 | $P^H$ | 12.5(saturated paste) |
| 3 | S | $SO_3$ | 9-11 | Specific gravity | 2.5 |
| 4 | Al | $Al_2O_3$ | 5-7 | Solubility | In water 0.2pts/100pt |
| 5 | Fe | $Fe_2O_3$ | 0-2 | Freezing point | None, Solid |
| 6 | Mg | MgO | 0-1 | Flammability | Non-Flammable |
| 7 | Mn,K,Cu, Zn | Mn,K,Cu,Zn | 0-3 | Shelf life | 12 month(Dry storage) |
| 8 | Fibers(Poly propylene) | | 0-1 | Storage | Dry storage avoid moisture contact |
| 9 | Additives | | 0-4 | Bulk density | 700kg/$m^3$ |

Table: 01

Uses of RBI Grade 81

*1)* Construction Time and Cost reduction.
*2)* Drastically increases the strength
*3)* Treated layers are water resistant.
*4)* Reduces thickness, use of transport, and earth- moving machinery substantially.
*5)* Longer Durability which reduces Maintenance.
*6)* RBI Grade-81 Pavement Material & a Natural Soil Stabilizer.
*7)* Reduces leaching and use of bitumen.
*8)* Reduces energy consumption.
*9)* Saves material like Aggregates/Good soil/bitumen.
*10)* Reduces Carbon Emission enabling, carbon credits.

*C. Sodium silicate*

Sodium silicate grouts are the most popular grouts due to their environmental and safety compatibility. Moreover, sodium silicates have been developed into a wide variety of different grout systems. Practically, all systems are assumed on reacting a silicate solution to form a colloid which polymerizes further to form a gel that binds sediment particles or soil together and fill voids. Sodium silicate grouts have been used to cut off water flowing through permeable foundations and to stabilize or strengthen foundations composed of fracture rock and granular materials. Also, granular materials that have been saturated with silicate grout develop quite low hydraulic conductivity if the gel is not allowed to dry out and shrink.

Even though shrinkage may occur, a low degree of hydraulic conductivity is usually obtained. Treatment with Sodium silicate grout will enhance the strength and the load bearing capacity of any groutable granular material coarser than the 75-µm sieve. Factors that influence strength are particle size distribution, Grain size, particle shape, the ability of the grout to adhere to the particle surfaces, absorption, moisture content, method of loading and curing environment. Also Sodium silicate solutions are basic. As this alkaline solution is neutralized, colloidal silica will aggregate to form a gel if the sodium silicate is present in concentrations above 1 or 2% (by volume). Sodium silicate and a reactant solution can be injected as separate solutions, or the sodium silicate can be premixed with the reactant to form a single solution that is injected.

*1) Composition of Sodium silicate*

| Sr.no | Particulars | Value |
|---|---|---|
| 1 | Total Alkalinity($Na_2O$) | 11.55 |
| 2 | Silicate($Sio_2$) | 28.12 |
| 3 | Ratio by weight $Na_2O:SiO_2$ | 1 to 2.43 |
| 4 | Molecular ratio $Na_2O:SiO_2$ | 1 to 1.66 |

*a)* Sodium silicate grouts are the most popular grouts because of their environmental compatibility and safety.
*b)* Sodium Silicate is considered for use as a stabilizing agent to improve the mixability of the soil in situ and in this way increase the homogeneity and strength of stabilized soils.
*c)* Sodium silicate should be mixed with the soil before the binder is added. It is important that this admixture in itself does not have a negative effect on the hydration processes.
*d)* Sodium silicate is sometimes used in applications where a reduction in the bulk density is desired, and may thereby have a certain negative effect on strength.
*e)* Sodium silicates can increase the strength and durability of sandy and silty soils, but they only increase the short-term strength of clays stabilized with cement, lime or lime-fly ash

## II. JUSTIFICATION OF PROJECT WORK

Almost 20% of land in India is roofed by expansive soils. With the rapid growth in industrialization and urbanization, land scarcity appears to be an imminent threat. Construction of civil engineering structures on expansive soils, however pose a major risk to the structure in itself, because of the greater degree of instability in these kinds of soil. Tallied in billions of dollars is the loss in property every year globally owing to the instability in the expansive soils.
RBI Grade 81 is composed of a number of naturally occurring compounds. It is particularly effective in the stabilization of black cotton soil. The reaction of RBI Grade 81 with soil particles produces as an inter-particle matrix that binds the soil particles together into a rigid mass. Sodium silicate is considered for use as a stabilizing agent to improve the mixability of the in-situ soil and in this way increase the homogeneity and strength of stabilized soils. Keeping the above issues in mind, this project work of stabilization of black cotton soil by using RBI Grade 81 and Sodium silicate is justified.

## III. OBJECTIVE OF PROJECT WORK

*1)* To check the ambit of reducing expansiveness and improving the Unconfined Compressive Strength of black cotton soil by adding the admixtures of RBI Grade 81 and Sodium silicate.
*2)* Improving the California Bearing Ratio of Black cotton soil by adding the admixtures of RBI Grade 81 and Sodium silicate.

## IV. SCOPE OF WORK

The experimental work in this project work consists of the following tests:
*1)* Determination of natural water content of soil.
*2)* Determination of differential free swell index of soil.
*3)* Determination of specific gravity of soil.
*4)* Determination of particle size distribution of soil by sieve analysis.
*5)* Determination of soil index properties (Atterberg's Limits)

*a)* Liquid limit by Casagrande's apparatus.
*b)* Plastic limit.
*6)* Determination of the maximum dry density (MDD) and the corresponding optimummoisture content (OMC) of the soil by Standard Proctor's compaction test.
*7)* Determination of the shear strength of soil by Unconfined compressive strength test.
*8)* Determination of California Bearing Ratio of soil.

*A. Materials*

*1)* Soil sample location: Black cotton soil from the Industrial Estate in Bhimavaram.
*2)* RBI Grade 81(Powder form): Alchemist Technology Limited, Gurgaon, Haryana.
*3)* Sodium silicate (Liquid form 5mol/L): Organ Refractories, Khammam,Telangana.

## V. PREPARATION OF SAMPLES

Following steps are carried out while mixing the RBI Grade 81 to the soil

*1)* All the soil samples are compacted at their respective maximum dry density (MDD) and optimum moisture content (OMC), corresponding to the Standard Proctor's compaction test
*2)* The RBI Grade 81material is added to black cotton soil at 2%, 4% and 6%.
*3)* The Sodium silicate solution is added to Black cotton soil at 3%, 4.5% and 6%.

*A. Determination of natural water content of Black cotton soil*

| *Sr.No* | *Description* | *Value* |
|---|---|---|
| 1. | Empty weight of container ($W_1$) gm | 22.42 |
| 2. | Weight of container + wet soil ($W_2$) gm | 63.86 |
| 3. | Weight of container + dry soil ($W_3$) gm | 58.95 |
| 4. | Water content (w) | 13.44% |

Table: 05 The natural water content of Black cotton soil = 13.44

*B. Differential free swell of Black cotton Soil*

| Determinationno. | Measuring cylinder reading | | Reading after 24 hours | | Differentialfree swell index (%) |
|---|---|---|---|---|---|
| | Kerosene (ml) | Distilled water (ml) | Kerosene (ml) | Distilled water (ml) | |
| 1 | 8 | 8 | 8 | 14 | 75 |
| 2 | 8 | 8 | 8 | 14 | 75 |
| 3 | 8 | 8 | 8 | 14 | 75 |

Table: 06

*1) Differential free swell of Black cotton soil with 2% RBI Grade 81*

| Determinationno. | Measuring cylinder reading | | Reading after 24 hours | | Differential free swellindex (%) |
|---|---|---|---|---|---|
| | Kerosene (ml) | Distilled water (ml) | Kerosene (ml) | Distilled water (ml) | |
| 1 | 8 | 8 | 8 | 13 | 62.50 |
| 2 | 8 | 8 | 8 | 13 | 62.50 |
| 3 | 8 | 8 | 8 | 13 | 62.50 |

Table: 07

*2) Differential free swell of Black cotton soil with 4% RBI Grade 81*

| Determinationno. | Measuring cylinder reading | | Reading after 24 hours | | Differentialfree swell index (%) |
|---|---|---|---|---|---|
| | Kerosene (ml) | Distilled water (ml) | Kerosene (ml) | Distilled water (ml) | |
| 1 | 8 | 8 | 8 | 12.50 | 56.25 |
| 2 | 8 | 8 | 8 | 12.50 | 56.25 |
| 3 | 8 | 8 | 8 | 12.50 | 56.25 |

Table: 08

*3) Differential free swell of Black cotton soil with 6% RBI Grade 81*

| Determination no. | Measuring cylinder reading | | Reading after 24 hours | | Differentialfree swell index (%) |
|---|---|---|---|---|---|
| | Kerosene (ml) | Distilled water (ml) | Kerosene (ml) | Distilled water (ml) | |
| 1 | 8 | 8 | 8 | 12 | 50 |
| 2 | 8 | 8 | 8 | 12 | 50 |
| 3 | 8 | 8 | 8 | 12 | 50 |

Table: 09

*4) Differential free swell of Black cotton soil with 3% Sodium silicate*

| Determinationno. | Measuring cylinder reading | | Reading after 24 hours | | Differentialfree swell index (%) |
|---|---|---|---|---|---|
| | Kerosene (ml) | Distilled water (ml) | Kerosene (ml) | Distilled water (ml) | |
| 1 | 8 | 8 | 8 | 15 | 87.50 |
| 2 | 8 | 8 | 8 | 15 | 87.50 |
| 3 | 8 | 8 | 8 | 15 | 87.50 |

Table: 10

*5) Differential free swell of Black cotton soil with 4.5% Sodium silicate*

| Determinationno. | Measuring cylinder reading | | Reading after 24 hours | | Differentialfree swell index (%) |
|---|---|---|---|---|---|
| | Kerosene (ml) | Distilled water (ml) | Kerosene (ml) | Distilled water (ml) | |
| 1 | 8 | 8 | 8 | 15 | 87.50 |
| 2 | 8 | 8 | 8 | 15 | 87.50 |
| 3 | 8 | 8 | 8 | 15 | 87.50 |

Table: 11

*6) Differential free swell of Black cotton soil with 6% Sodium silicate*

| Determinationno. | Measuring cylinder reading | | Reading after 24 hours | | Differentialfree swell index (%) |
|---|---|---|---|---|---|
| | Kerosene (ml) | Distilled water (ml) | Kerosene (ml) | Distilled water (ml) | |
| 1 | 8 | 8 | 8 | 14.50 | 81.25 |
| 2 | 8 | 8 | 8 | 14.50 | 81.25 |
| 3 | 8 | 8 | 8 | 14.50 | 81.25 |

Table: 12

*C. Specific gravity of Black cotton soil*

| Sample Number | | | 1 | 2 | 3 |
|---|---|---|---|---|---|
| Mass of empty specific gravity bottle (M1) | | gm | 27.14 | 27.14 | 27.14 |
| Mass of Sp.gr bottle+ dry soil | (M2) | gm | 48.57 | 51.37 | 47.83 |
| Mass of Sp.gr bottle+ dry soil+ water (M3) | | gm | 91.90 | 93.67 | 91.48 |
| Mass of Sp.gr bottle+ water | (M4) | gm | 78.46 | 78.62 | 78.59 |
| Specific gravity of soil sample | | | 2.68 | 2.64 | 2.65 |
| Average Specific gravity | | | 2.66 | | |

Table: 13The Specific gravity of Black cotton soil = 2.66

*D. Sieve analysis of Black cotton soil*

| IS Sieve size(mm) | Weight of material retained(gm) | Percent retained(%) | Cumulative percent retained(%) | Percent passingthrough (%) |
|---|---|---|---|---|
| 4.75 | 0 | 0 | 0 | 100 |
| 2.00 | 7.0 | 0.7 | 0.7 | 99.30 |
| 1.00 | 13.5 | 1.35 | 2.05 | 97.95 |
| 0.6 | 22.5 | 2.25 | 4.30 | 95.70 |
| 0.3 | 28.5 | 2.85 | 7.15 | 92.85 |
| 0.15 | 31.5 | 3.15 | 10.30 | 89.70 |
| 0.075 | 38.0 | 3.80 | 14.10 | 85.90 |

Table: 14

*E. Liquid limit of Black cotton soil*

| Sample Number | | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|
| Mass of empty container | (M1) | gm | 20.62 | 21.47 | 20.97 | 20.78 | 21.72 |
| Mass of container + wet soil | (M2) | gm | 51.72 | 56.88 | 61.72 | 57.56 | 64.12 |
| Mass of container + dry soil | (M3) | gm | 38.02 | 42.14 | 46.06 | 43.99 | 49.47 |
| Water content | (%) | | 78.73 | 71.31 | 62.41 | 58.46 | 52.79 |
| Number of blows | | | 11 | 17 | 27 | 36 | 45 |

Table: 15

The Liquid limit of Black cotton soil = 62.50 %

*1) Liquid limit of Black cotton soil with 2% RBI Grade 81*

| Sample Number | | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|
| Mass of empty container | (M1) | gm | 20.32 | 20.84 | 21.36 | 20.72 | 21.64 |
| Mass of container + wet soil | (M2) | gm | 51.86 | 53.66 | 56.24 | 52.82 | 54.58 |
| Mass of container + dry soil | (M3) | gm | 38.36 | 40.32 | 43.14 | 41.22 | 43.01 |
| Water content | (%) | | 74.83 | 68.48 | 60.15 | 56.58 | 54.14 |
| Number of blows | | | 10 | 15 | 29 | 35 | 43 |

Table: 16

The Liquid limit of Black cotton soil with 2% RBI Grade 81= 60 %

 

*2) Liquid limit of Black cotton soil with 4% RBI Grade 81*

| Sample Number | | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|
| Mass of empty container | (M1) | gm | 20.54 | 20.72 | 20.62 | 20.38 | 21.66 |
| Mass of container + wet soil (M2) | | gm | 51.72 | 57.61 | 61.06 | 58.07 | 57.08 |
| Mass of container + dry soil (M3) | | gm | 38.39 | 42.66 | 46.23 | 45.14 | 45.38 |
| Water content | (%) | | 74.68 | 68.14 | 57.91 | 52.22 | 49.33 |
| Number of blows | | | 12 | 18 | 28 | 38 | 47 |

Table: 17

The Liquid limit of Black cotton soil with 4% RBI Grade 81= 59.50 %

*3) Liquid limit of Black cotton soil with 6% RBI Grade 81*

| Sample Number | | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|
| Mass of empty container | (M1) | gm | 20.23 | 20.36 | 20.42 | 21.26 | 21.16 |
| Mass of container + wet soil | (M2) | gm | 50.19 | 50.41 | 51.08 | 52.31 | 52.63 |
| Mass of container + dry soil | (M3) | gm | 37.63 | 38.91 | 39.84 | 41.71 | 42.12 |
| Water content | (%) | | 72.18 | 61.99 | 57.88 | 51.83 | 50.14 |
| Number of blows | | | 11 | 16 | 29 | 36 | 42 |

Table: 18

The Liquid limit of Black cotton soil with 6% RBI Grade 81= 57.50 %

*4) Liquid limit of Black cotton soil with 3% Sodium silicate*

| Sample Number | | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|
| Mass of empty container | (M1) | gm | 20.94 | 20.75 | 20.21 | 21.01 | 21.64 |
| Mass of container + wet soil (M2) | | gm | 50.87 | 50.71 | 50.54 | 51.23 | 51.67 |
| Mass of container + dry soil (M3) | | gm | 37.47 | 38.35 | 38.90 | 40.01 | 41.61 |
| Water content | (%) | | 81.06 | 70.23 | 62.28 | 59.05 | 50.37 |
| Number of blows | | | 10 | 15 | 27 | 36 | 44 |

Table: 19

The Liquid limit of Black cotton soil with 3% Sodium silicate = 61%

*5) Liquid limit of Black cotton soil with 4.5% Sodium silicate*

| Sample Number | | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|
| Mass of empty container | (M1) | gm | 20.12 | 20.54 | 20.90 | 21.29 | 21.92 |
| Mass of container + wet soil | (M2) | gm | 50.31 | 50.72 | 51.01 | 52.65 | 52.98 |
| Mass of container + dry soil | (M3) | gm | 36.72 | 37.57 | 38.98 | 40.85 | 41.50 |
| Water content | (%) | | 81.86 | 77.22 | 66.54 | 60.33 | 58.63 |
| Number of blows | | | 10 | 14 | 26 | 35 | 43 |

Table: 20

The Liquid limit of Black cotton soil with 4.5% Sodium silicate = 65%

*6) Liquid limit of Black Cotton Soil with 6% Sodium silicate*

| Sample No. | | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|
| Mass of empty container | (M1) | gm | 20.91 | 21.19 | 20.15 | 21.61 | 20.83 |
| Mass of container + wet soil | (M2) | gm | 50.35 | 51.91 | 50.66 | 52.29 | 50.26 |
| Mass of container + dry soil | (M3) | gm | 37.43 | 39.14 | 39.06 | 41.20 | 40.44 |
| Water content | (%) | | 78.21 | 71.14 | 61.34 | 56.61 | 50.08 |
| Number of blows | | | 9 | 18 | 27 | 34 | 46 |

Table: 21

The Liquid limit of Black cotton soil with 6% Sodium silicate = 59%

*F. Plastic limit of Black cotton soil*

| Sample Number | | | 1 | 2 | 3 |
|---|---|---|---|---|---|
| Mass of empty container | (M1) | gm | 19.29 | 18.27 | 20.12 |
| Mass of container + wet soil | (M2) | gm | 50.02 | 46.80 | 45.30 |
| Mass of container + dry soil | (M3) | gm | 41.80 | 39.19 | 38.56 |
| Water content | (%) | | 36.52 | 36.38 | 36.56 |
| Plastic limit | | | 36.49 | | |

Table: 22

*1) Plastic limit of Black cotton soil with 2% RBI Grade 81*

| Sample Number | | | 1 | 2 | 3 |
|---|---|---|---|---|---|
| Mass of empty container | (M1) | gm | 18.86 | 19.32 | 20.76 |
| Mass of container + wet soil | (M2) | gm | 49.12 | 40.74 | 51.32 |
| Mass of container + dry soil | (M3) | gm | 40.80 | 34.85 | 42.93 |
| Water content | (%) | | 37.92 | 37.93 | 37.85 |
| Plastic limit | | | 37.90 | | |

Table: 23

*2) Plastic limit of Black cotton soil with 4% RBI Grade 81*

| Sample Number | | | 1 | 2 | 3 |
|---|---|---|---|---|---|
| Mass of empty container | (M1) | gm | 19.15 | 20.47 | 18.82 |
| Mass of container + wet soil | (M2) | gm | 51.32 | 47.95 | 42.95 |
| Mass of container + dry soil | (M3) | gm | 42.33 | 40.27 | 36.21 |
| Water content | (%) | | 38.78 | 38.78 | 38.76 |
| Plastic limit | | | 38.77 | | |

Table: 24

*3) Plastic limit of Black cotton soil with 6% RBI Grade 81*

| Sample Number | | | 1 | 2 | 3 |
|---|---|---|---|---|---|
| Mass of empty container | (M1) | gm | 20.26 | 18.12 | 19.48 |
| Mass of container + wet soil | (M2) | gm | 51.10 | 48.21 | 50.07 |
| Mass of container + dry soil | (M3) | gm | 42.85 | 40.12 | 41.87 |
| Water content | (%) | | 36.52 | 36.77 | 36.62 |
| Plastic limit | | | 36.64 | | |

Table: 25

*4) Plastic limit of Black cotton soil with 3% Sodium silicate*

| Sample Number | | | 1 | 2 | 3 |
|---|---|---|---|---|---|
| Mass of empty container | (M1) | gm | 19.65 | 20.71 | 18.54 |
| Mass of container + wet soil | (M2) | gm | 49.89 | 50.16 | 49.26 |
| Mass of container + dry soil | (M3) | gm | 40.70 | 41.22 | 39.94 |
| Water content | (%) | | 43.66 | 43.59 | 43.55 |
| Plastic limit | | | 43.60 | | |

Table: 26

*5) Plastic limit of Black cotton soil with 4.5% Sodium silicate*

| Sample Number | | | 1 | 2 | 3 |
|---|---|---|---|---|---|
| Mass of empty container | (M1) | gm | 18.49 | 19.62 | 20.33 |
| Mass of container + wet soil | (M2) | gm | 49.07 | 50.33 | 51.35 |
| Mass of container + dry soil | (M3) | gm | 38.35 | 39.59 | 40.56 |
| Water content | (%) | | 53.98 | 53.78 | 53.34 |
| Plastic limit | | | 53.70 | | |

Table: 27

*6) Plastic limit of Black cotton soil with 6% Sodium silicate*

| Sample Number | | | 1 | 2 | 3 |
|---|---|---|---|---|---|
| Mass of empty container | (M1) | gm | 18.49 | 19.26 | 20.22 |
| Mass of container + wet soil | (M2) | gm | 50.47 | 51.34 | 52.72 |
| Mass of container + dry soil | (M3) | gm | 39.82 | 40.60 | 41.62 |
| Water content | (%) | | 49.92 | 50.33 | 51.87 |
| Plastic limit | | | 50.71 | | |

Table: 28

*G. Plasticity Index of Black cotton soil*

$I_P = W_L - W_P = 62.50\text{-}36.49$

$\therefore I_P = 26.01\%$

*1) Plasticity Index of Black cotton soil with 2% RBI Grade 81*

$I_P = W_L - W_P = 60\text{-}37.90$

$\therefore I_P = 22.10\%$

*2) Plasticity Index of Black cotton soil with 4% RBI Grade 81*

$I_P = W_L - W_P = 59.50\text{-}38.77$

$\therefore I_P = 20.73\%$

*3) Plasticity Index of Black cotton soil with 6% RBI Grade 81*

$I_P = W_L - W_P = 57.50\text{-}36.64$

$\therefore I_P = 20.86\%$

*4) Plasticity Index of Black cotton soil with 3% Sodium silicate*

$I_P = W_L - W_P = 61\text{-}43.60$

$\therefore I_P = 17.40\%$

*5) Plasticity Index of Black cotton soil with 4.5% Sodium silicate*

$I_P = W_L - W_P = 65\text{-}53.70$

$\therefore I_P = 11.30\%$

*6) Plasticity Index of Black cotton soil with 6% Sodium silicate*

$I_P = W_L - W_P = 59\text{-}50.71$

$\therefore I_P = 8.29\%$

 

*H. Standard Proctor's compaction test of Black cotton soil*

| Test No. | | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Weight of empty mould (W1) | gm | 5751 | 5751 | 5751 | 5751 |
| Volume of mould (V) | $cm^3$ | 1000 | 1000 | 1000 | 1000 |
| Weight of mould + compacted soil (W2) | gm | 7757 | 7834 | 7878 | 7888 |
| Weight of compacted soil (W2-W1) | gm | 2006 | 2083 | 2127 | 2137 |
| Bulk density of compacted soil**ρ**= (W2 - W1)/V | $gm/cm^3$ | 2.006 | 2.083 | 2.127 | 2.137 |

| Container No. | | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Weight of empty container(X1) | gm | 20.84 | 20.95 | 19.77 | 20.31 |
| Weight of container + wet soil (X2) | gm | 81.96 | 93.94 | 94.71 | 92.50 |
| Weight of container + dry soil (X3) | gm | 72.01 | 80.87 | 80.36 | 77.72 |
| Water content = w = (X2-X3)/(X3 – X1)X 100 | ( % ) | 19.46 | 21.82 | 23.68 | 25.74 |
| Dry density of compacted soil $\rho_d$ = ρ/(1 + w) | $gm/cm^3$ | 1.68 | 1.71 | 1.72 | 1.70 |

Table: 29

1.The optimum moisture content of Black cotton soil = OMC= 23.68 %

2. The maximum dry density of Black cotton soil = MDD= 1.72 $gm/cm^3$

*1) Standard Proctor's compaction test of Black cotton soil with 2% RBIGrade 81*

| Test No. | | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Weight of empty mould (W1) | gm | 5751 | 5751 | 5751 | 5751 |
| Volume of mould (V) | $cm^3$ | 1000 | 1000 | 1000 | 1000 |
| Weight of mould + compacted soil (W2) | gm | 7784 | 7834 | 7876 | 7890 |
| Weight of compacted soil (W2-W1) | gm | 2033 | 2083 | 2125 | 2139 |
| Bulk density of compacted soil**ρ**= (W2 - W1)/V | $gm/cm^3$ | 2.033 | 2.083 | 2.125 | 2.139 |

| Container No. | | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Weight of empty container(X1) | gm | 18.77 | 20.16 | 20.84 | 20.57 |
| Weight of container + wet soil (X2) | gm | 80.67 | 83.29 | 84.04 | 83.95 |
| Weight of container + dry soil (X3) | gm | 69.31 | 70.77 | 70.80 | 70.04 |
| Water content = w = (X2-X3)/(X3 – X1)X 100 | ( % ) | 22.48 | 24.74 | 26.50 | 28.12 |
| Dry density of compacted soil $\rho_d$ = ρ/(1 + w) | $gm/cm^3$ | 1.66 | 1.67 | 1.68 | 1.67 |

Table: 30

1.The optimum moisture content of Black cotton soil with2% RBI Grade 81 = OMC= 26.50 %

2. The maximum dry density of Black cotton soil with2% RBI Grade 81 = MDD= 1.68 $gm/cm^3$

*2) Inferences from Differential free swell index*

*a)* Due to 2% RBI Grade 81, the Differential free swell index of Black cotton soil decreases from 75% to 62.5% i.e., a net of 16.66%.
*b)* Due to 4% RBI Grade 81, the Differential free swell index of Black cotton soil decreases from 75% to 56.25% i.e., a net of 25%.
*c)* Due to 6% RBI Grade 81, the Differential free swell index of Black cotton soil decreases from 75% to 50% i.e., a net of 33.33%.
*d)* Due to 3% Sodium silicate, the Differential free swell index of Black cotton soil increases from 75% to 87.50% i.e., a net of 16.66%.
*e)* Due to 4.5% Sodium silicate, the Differential free swell index of Black cotton soil increases from 75% to 87.50% i.e., a net of 16.66%.
*f)* Due to 6% Sodium silicate, the Differential free swell index of Black cotton soil increases from 75% to 81.25% i.e., a net of 8.33%.

*3) Inferences from Liquid limit*

*a)* Due to 2% RBI Grade 81, the Liquid limit of Black cotton soil decreases from 62.50% to 60.00% i.e., a net of 4%.
*b)* Due to 4% RBI Grade 81, the Liquid limit of Black cotton soil decreases from 62.50% to 59.50% i.e., a net of 4.8%.
*c)* Due to 6% RBI Grade 81, the Liquid limit of Black cotton soil decreases from 62.50% to 57.50% i.e., a net of 8%.
*d)* Due to 3% Sodium silicate, the Liquid limit of Black cotton soil decreases from 62.50% to 61.00% i.e., a net of 2.4%.
*e)* Due to 4.5% Sodium silicate, the Liquid limit of Black cotton soil increases from 62.50% to 65.00% i.e., a net of 4%.
*f)* Due to 6% Sodium silicate, the Liquid limit of Black cotton soil decreases from 62.50% to 59.00% i.e., a net of 5.6%.

*4) Inferences from Plasticity index*

*a)* Due to 2% RBI Grade 81, the Plasticity index of Black cotton soil decreases from 26.01% to 22.10% i.e., a net of 15.03%.
*b)* Due to 4% RBI Grade 81, the Plasticity index of Black cotton soil decreases from 26.01% to 20.73% i.e., a net of 20.29%.
*c)* Due to 6% RBI Grade 81, the Plasticity index of Black cotton soil decreases from 26.01% to 20.86% i.e., a net of 19.80%.
*d)* Due to 3% Sodium silicate, the Plasticity index of Black cotton soil decreases from 26.01% to 17.40% i.e., a net of 33.10%.
*e)* Due to 4.5% Sodium silicate, the Plasticity index of Black cotton soil decreases from 26.01% to 11.30% i.e., a net of 56.55%.
*f)* Due to 6% Sodium silicate, the Plasticity index of Black cotton soil decreases from 26.01% to 8.29% i.e., a net of 68.12%.

*5) Inferences from Optimum moisture content*

*a)* Due to 2% RBI Grade 81, the Optimum moisture content of Black cotton soil increases from 23.68% to 26.50% i.e., a net of 11.91%.
*b)* Due to 4% RBI Grade 81, the Optimum moisture content of Black cotton soil increases from 23.68% to 27.80% i.e., a net of 17.40%
*c)* Due to 6% RBI Grade 81, the Optimum moisture content of Black cotton soil increases from 23.68% to 24.86% i.e., a net of 4.98%.

*6) Inferences from Maximum dry density*

*a)* Due to 2% RBI Grade 81, the Maximum dry density of Black cotton soil decreases from 1.72 gm/cm3 to 1.68 gm/cm3 i.e., a net of 2.32%.
*b)* Due to 4% RBI Grade 81, the Maximum dry density of Black cotton soil increases from 1.72 gm/cm3 to 1.95 gm/cm3 i.e., a net of 13.37%
*c)* Due to 6% RBI Grade 81, the Maximum dry density of Black cotton soil increases from 1.72 gm/cm3 to 1.82 gm/cm3 i.e., a net of 5.81%.

*7) Inferences from Unconfined compressive strength*

*a)* Due to 2% RBI Grade 81, the Unconfined compressive strength of Black cotton soil increases from 0.285 Mpa to 0.312 Mpa i.e., a net of 9.47%.
*b)* Due to 4% RBI Grade 81, the Unconfined compressive strength of Black cotton soil increases from 0.285 Mpa to 0.412 Mpa

i.e., a net of 44.56%.

*c)* Due to 6% RBI Grade 81, the Unconfined compressive strength of Black cotton soil increases from 0.285 Mpa to 0.493 Mpa i.e., a net of 72.98%.

*d)* Due to 3% Sodium silicate, the Unconfined compressive strength of Black cotton soil increases from 0.285 Mpa to 0.412 Mpa i.e., a net of 44.56%.

*e)* Due to 4.5% Sodium silicate, the Unconfined compressive strength of Black cotton soil increases from 0.285 Mpa to 0.496 Mpa i.e., a net of 74.04%.

*f)* Due to 6% Sodium silicate, the Unconfined compressive strength of Black cotton soil increases from 0.285 Mpa to 0.372 Mpa i.e., a net of 30.53%.

*8) Inferences from California bearing ratio*

*a)* Due to 2% RBI Grade 81, the California bearing ratio of Black cotton soil increases from 2.86 to 8.30 i.e., a net of 190.20%.

*b)* Due to 4% RBI Grade 81, the California bearing ratio of Black cotton soil increases from 2.86 to 16.50 i.e., a net of 476.92%.

*c)* Due to 6% RBI Grade 81, the California bearing ratio of Black cotton soil increases from 2.86 to 20.30 i.e., a net of 609.80%.

*d)* Due to 3% Sodium silicate, the California bearing ratio of Black cotton soil decreases from 2.86 to 2.42 i.e., a net of 15.38%.

*e)* Due to 4.5% Sodium silicate, the California bearing ratio of Black cotton soil decreases from 2.86 to 1.98 i.e., a net of 30.77 %.

*f)* Due to 6% Sodium silicate, the California bearing ratio of Black cotton soil decreases from 2.86 to 1.98 i.e., a net of 30.77%.

## VI. DISCUSSIONS

Black cotton soil is combined with altering percentages of RBI Grade 81 (2%, 4% & 6%) and Sodium silicate (3%, 4.5% & 6%) by weight to observe their effect as an additives on the expansive soils.

*1)* Differential free swell index was found to change with varying percentages of RBI Grade 81. The minimum value is observed for RBI Grade 81 content at 6% by weight.

*2)* Differential free swell index was found to change with varying percentages of Sodium silicate. The maximum value is observed for Sodium silicate content at 3% by weight.

*3)* Liquid limit was found to change with varying percentages of RBI Grade 81. The minimum value is observed for RBI Grade 81 content at 6% by weight.

*4)* Liquid limit was found to change with varying percentages of Sodium silicate. The maximum value is observed for Sodium silicate content at 4.5% by weight.

*5)* Plasticity index was found to change with varying percentages of RBI Grade 81. The minimum value is observed for RBI Grade 81 content at 4% by weight.

*6)* Plasticity index was found to change with varying percentages of Sodium silicate. The minimum value is observed for Sodium silicate content at 6% by weight.

*7)* Optimum moisture content was found to change with varying percentages of RBI Grade 81.The maximum value is observed for RBI Grade 81 content is at 4% by weight.

*8)* Maximum dry density was found to change with varying percentages of RBI Grade 81. The maximum value is observed for RBI Grade 81 content is at 4% by weight.

*9)* Unconfined compressive strength was found to change with varying percentages of RBI Grade 81. The maximum value is observed for RBI Grade 81 content is at 6% by weight.

*10)* Unconfined compressive strength was found to change with varying percentages of Sodium silicate. The maximum value is observed for Sodium silicate content is at 4.5% by weight.

*11)* The California bearing ratio was found to change with varying percentages of RBI Grade 81. The maximum value is observed for RBI Grade 81 content is at 6% by weight.

*12)* The California bearing ratio was found to change with varying percentages of Sodium silicate. The minimum value is observed for Sodium silicate content is at 6% by weight.

## VII. CONCLUSIONS

Based on the results obtained and comparisons made in the present project work, the following conclusions can be drawn.

*1)* The Differential free swell index of Black cotton soil changes with addition of the RBI Grade 81. It showed a decrement with increase of RBI Grade 81 content in the soil – RBI Grade 81 mixture. The minimum value of Differential free swell index was observed for a mixture of soil and 6% of RBI Grade 81 content by weight.

2) The Differential free swell index of Black cotton soil changes with addition of the Sodium silicate. It showed an increment with increase of Sodium silicate content in the soil – Sodium silicate mixture. The maximum value of Differential free swell index was observed for a mixture of soil and 4.5% of Sodium silicate content by weight.
3) The Liquid limit of Black cotton soil changes with addition of RBI Grade 81. It showed a decrement with increase of RBI Grade 81 content in the soil – RBI Grade 81 mixture. The minimum value of Liquid limit was observed for a mixture of soil and 6% of RBI Grade 81 content by weight.
4) The Liquid limit of Black cotton soil Varies with addition of the Sodium silicate. It showed an increment at 4.5% of Sodium silicate and a decrement at 3% and 6% of Sodium silicate. The maximum value of Liquid limit was observed for a mixture of soil and 4.5% of Sodium silicate content by weight and the minimum value was observed for a mixture of soil and 6% of Sodium silicate content by weight.
5) The Plasticity index of Black cotton soil changes with addition of the RBI Grade 81. It showed a decrement with increase of RBI Grade 81 content in the soil – RBI Grade 81 mixture. The minimum value of Plasticity index was observed for a mixture of soil and 4% of RBI Grade 81 content by weight.
6) The Plasticity index of Black cotton soil changes with addition of the Sodium silicate. It showed a decrement with increase of Sodium silicate content in the soil – Sodium silicate mixture. The minimum value of Plasticity index was observed for a mixture ofsoil and 6% of Sodium silicate content by weight.
7) The Optimum moisture content of Black cotton soil changes with addition of the RBI Grade 81. It showed an increment and decrement with increase of RBI Grade 81 content in the soil – RBI Grade 81 mixture. The maximum value of Optimum
8) Moisture content was observed for a mixture of soil and 4% of RBI Grade 81 content by weight.
9) The Maximum dry density of Black cotton soil changes with addition of the RBI Grade 81. It showed a decrement at 2% of RBI Grade 81 and an increment at 4% and 6% of RBI Grade 81. The maximum value of Maximum dry density was observed for a mixture of soil and 4% of RBI Grade 81 content by weight.
10) The Unconfined compressive strength of Black cotton soil changes with addition of the RBI Grade 81. It showed an increment with increase of RBI Grade 81 content in the soil – RBI Grade 81 mixture. The maximum value of Unconfined compressive strength was observed for a mixture of soil and 6% of RBI Grade 81 content by weight.
11) The Unconfined compressive strength of Black cotton soil changes with addition of the Sodium silicate. It showed an increment with increase of Sodium silicate content in the soil – Sodium silicate mixture. The maximum value of Unconfined compressive strength was observed for a mixture of soil and 4.5% of Sodium silicate content by weight.
12) The soaked California bearing ratio of Black cotton soil changes with addition of the RBI Grade 81. It showed an increment with increase of RBI Grade 81 content in the soil – RBI Grade 81 mixture. The maximum value of California bearing ratio was observed for a mixture of soil and 6% of RBI Grade 81 content by weight.
13) The soaked California bearing ratio of Black cotton soil changes with addition of the Sodium silicate. It showed a decrement with increase of Sodium silicate content in the soil – Sodium silicate mixture. The minimum value of California bearing ratio was observed for a mixture of soil and 6% of Sodium silicate content by weight.

Based on the experimental results of Unconfined compressive strength, it can be concluded that the addition of RBI Grade 81 and Sodium silicate has significant effect on the Unconfined compressive strength of Black cotton soil.

Also, the experimental results of California bearing ratio for the soil has significantly increased with addition of RBI Grade 81 and Sodium silicate.

Comparing the results, it can be concluded that RBI Grade 81 is a better additive than Sodium silicate for stabilization of Black cotton soil.

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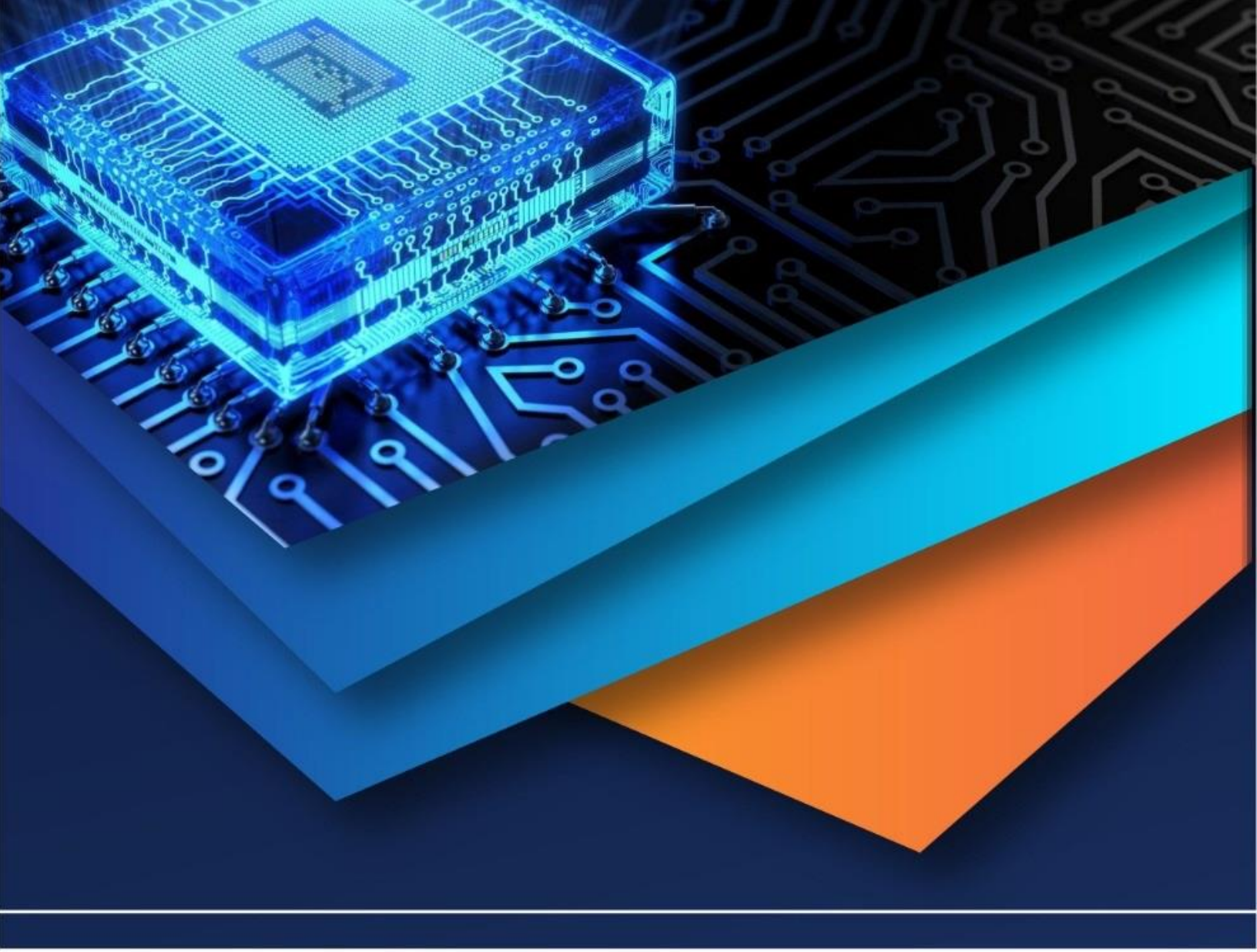

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