iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** VI **Month of publication:** June 2025

DOI: https://doi.org/10.22214/ijraset.2025.72521

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue VI June 2025- Available at www.ijraset.com

To Study the Impact of Chloride Compounds on the Characteristics of Clay Soil

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Abstract: ***This study investigates the impact of chloride compounds ($CaCl_2$, $MgCl_2$ and NaCl) on clay soil, aiming to provide valuable insights into the behavior and potential consequences of introducing chloride-based materials into clay-rich soil. Clay soils are prevalent in various regions worldwide and are known for their unique properties, including high plasticity and low permeability. Understanding how chloride compounds interact with clay soils is crucial for numerous fields, including geotechnical engineering, environmental science, and agriculture. The research involved laboratory experiments on clay soil samples added with varying concentrations (1%, 3%, and 5%) of chloride compounds ($CaCl_2$, $MgCl_2$, NaCl). Tests assessed physical and chemical changes in the soil, including consistency limits, optimum moisture content, maximum dry density, and unconfined compressive strength. Results showed that increasing chloride concentration led to a decrease in liquid limit, plastic limit, plasticity index, and optimum moisture content. Conversely, maximum dry density and unconfined compressive strength increased. Where, $CaCl_2$ consistently produced the greatest improvement in strength and reduction in plasticity, while NaCl had the mildest effect. These findings are relevant for both soil stabilization practices and understanding the environmental impact of saline intrusion.***

Keywords: Clay soil, $CaCl_2$, $MgCl_2$, NaCl, Consistency limits, OMC and MDD, Unconfined Compressive Strength (UCS), Soil Stabilization.

I. INTRODUCTION

Clay soil often poses challenges in construction due to their expansive nature, high plasticity, and low strength. Chemical stabilization, particularly using salts, has been investigated as a cost-effective method to improve these properties. Among salts, chloride compounds such as sodium chloride (NaCl), calcium chloride ($CaCl_2$), and magnesium chloride ($MgCl_2$) are commonly available and can affect the physicochemical interaction between clay particles.

This research aims to assess the impact of three different chloride salts—NaCl, $CaCl_2$, and $MgCl_2$—each added separately to clay soil in concentrations of 1%, 3%, and 5% by dry weight. The goal is to quantify and compare how increasing levels of each salt affect key geotechnical properties. Despite the significance of this topic, the existing body of literature on the subject remains relatively limited and often fragmented. Previous studies have explored the individual effects of chloride ions on soil properties, but a comprehensive understanding of the overall impact of chloride compounds on clay soil is lacking. Furthermore, the potential long-term consequences of these interactions, both in terms of soil performance and environmental repercussions, have not been thoroughly investigated. Therefore, this study aims to fill this critical knowledge gap by conducting a comprehensive investigation into the effect of chloride compounds on clay soil. Through laboratory experiments and controlled conditions, we will explore the physical, chemical, and geotechnical changes that occur when different types and concentrations of chloride compounds are introduced to clay soil samples. This research will provide valuable insights into the behavior and responses of clay soils in the presence of chloride, contributing to a more informed and sustainable use of chloride-based materials in various application.

II. LITERATURE REVIEW

Soil stabilization has been a focal area in geotechnical engineering, especially for expansive clay soils that are prone to volume changes due to moisture fluctuations. Various chemical additives such as calcium chloride ($CaCl_2$), sodium chloride (NaCl), gypsum, and cement have been explored to enhance the geotechnical properties of such soils. The interactions between chloride compounds and clay soil have been widely studied due to their potential impact on soil structure and properties. Chloride compounds, such as calcium chloride ($CaCl_2$), sodium chloride (NaCl), and magnesium chloride ($MgCl_2$), are known to alter the physicochemical properties of clay soil. These compounds can modify the electrical double layer around clay particles, affecting soil dispersion and aggregation.

There are many studies have been done in previous years and provide reviews of about their results on different soil with different types of Chloride Compound and also with other chemicals like lime, gypsum etc. Abdullah Almajed et al. (2023)[1] Presented their work on the combined effect of Calcium Chloride and Cement on expansive soil material. They observed that the use of 4% to 8% of $CaCl_2$ with the addition of 2% cement indicated significant improvement in the swell potential, swell pressure and compressibility. Jayant Singh et al. (2020) [2] observed that the improvement in the engineering properties of clay soil by stabilizing it with Gypsum and Calcium Chloride. Falah H Rahil et al. (2019)[3] Did experiment by mixing the Clay soil with Sodium Chloride (NaCl) in different proportion like 0%, 5%, 10%, and 15% by weight. They observed slight increment in maximum dry unit weight for low plasticity soil while it increases up to 5% then decreases for high plasticity soil. Across the reviewed literature there are many chemical additive available in the market by mixing them with clay soil we can improve the various property. On the basis of comprehensive study we can find out the best chemical additive.

III. MATERIALS AND METHODS

A. Soil Sample

Soil for the experiment has been brought from a site 500 m from National Highway (NH 32 B), Mohanlal Ganj, Lucknow, Uttar Pradesh. Disturbed sample was obtained using manual excavation. Soil sample received from the field was dried in sun. The lumps of the soil were broken with wooden mallet. Organic matters like grass & roots and other impurities were removed.

Table 1: Properties of Native Soil

S. NO.	Soil Characteristics	Values/Specification
1	Relative Density (Specific Gravity)	2.65
2	Soil Classification: Grain size analysis	
	Coarse soils: Gravel/Boulder	0%
	Coarse soils: Sand	22.20%
	Fine Graded Soils: Silt and Clay	77.80%
3	Atterberg's Limits	
	Liquid Limit	55
	Plastic Limit	28.56
	Plasticity Index	26.44
4	Soil Classification as per IS 2720	CH
5	Optimum Moisture Content (OMC)	19.12%
6	Dry Density (MDD)	1.780 g/cc
7	Unconfined Compressive Strength(UCS)	1.75 g/cm^2
8	Free Swell Index (FSI)	55.02 %

B. Chloride Compounds

Each of the following salts was added separately to soil samples at 1%, 3%, and 5% by
Dry weight:

1) Sodium Chloride (NaCl)
2) Calcium Chloride ($CaCl_2$)
3) Magnesium Chloride ($MgCl_2$)

All these Chloride compound are purchased from SHIDDHIJI ENTERPRISES AISHBAGH LUCKNOW

C. Preparation of specimens

Three types of chloride compound were used including ($CaCl_2$, $MgCl_2$, and NaCl). Each one of these salts has to be dissolved in water and then mixed with soil. The soil Specimens have to be prepared by Light compaction proctor test procedures according to ASTM (American Society for Testing and Materials).

D. Test Performed

The following tests were conducted on untreated soil and each salt-treated sample:

1) Atterberg Limits (LL, PL, PI)
2) Standard Proctor Compaction Test
3) Unconfined Compressive Strength (UCS) Test

IV. RESULTS AND DISCUSSION

A. Effect on Atterberg Limits

Table 2: Variation of Atterberg limits

Description	Soil	$CaCl_2$			$MgCl_2$			NaCl		
		1%	3%	5%	1%	3%	5%	1%	3%	5%
Liquid Limit	55.00	51.50	47.13	42.91	52.50	49.50	45.86	52.95	51.37	49.50
Plastic Limit	28.56	26.58	24.05	21.55	27.06	25.06	23.06	27.56	26.06	24.56
Plasticity Index	26.44	24.92	23.08	21.36	25.44	24.44	23.44	25.39	25.31	24.94

B. Variation Graph of Plasticity Index

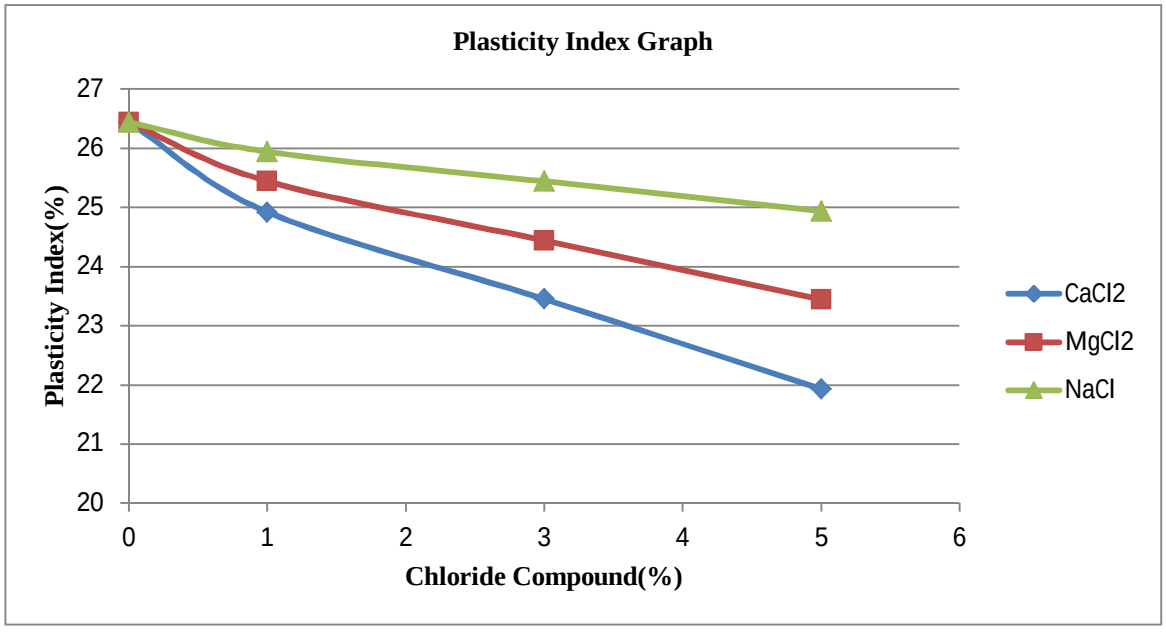

Fig.1. Variation Graph of Plasticity Index

From the above analysis as we increase the quantity of different Chloride compound ($CaCl_2$,$MgCl_2$ and NaCl) from 1% to 5% there are following changes occurs:-

- In case of $CaCl_2$ Plasticity Index is decreased by 17.05 %
- In case of MgCl2 Plasticity Index is decreased by 11.35 %
- In case of NaCl Plasticity Index is decreased by 5.67 %

C. Variation in OMC and MDD after mixing Chloride Compound with Soil

Table.3. Variation in OMC and MDD

Description	Soil	$CaCl_2$			$MgCl_2$			NaCl		
		1%	3%	5%	1%	3%	5%	1%	3%	5%
OMC	19.12	17.01	14.41	11.81	17.62	15.55	13.48	18.12	16.62	15.12
MDD	1.78	2.03	2.33	2.63	1.93	2.13	2.33	1.88	1.98	2.08

D. OMC Variation Graph

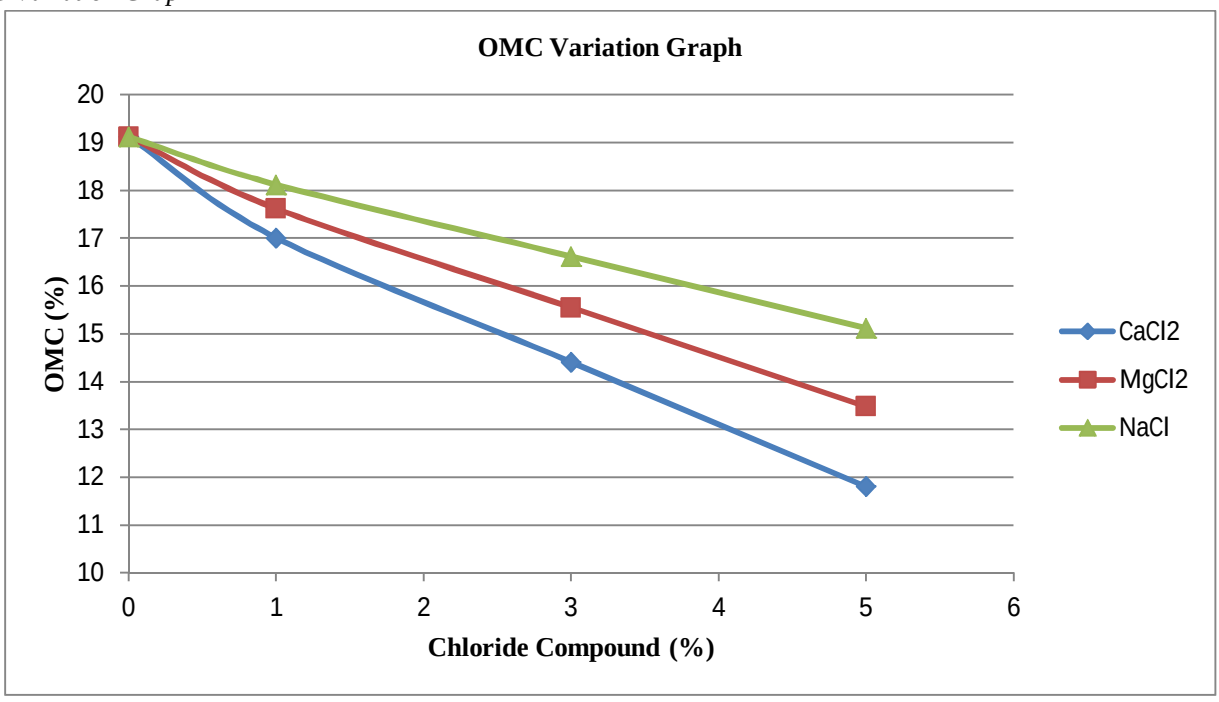

Fig.2. OMC Variation

E. MDD Variation Graph

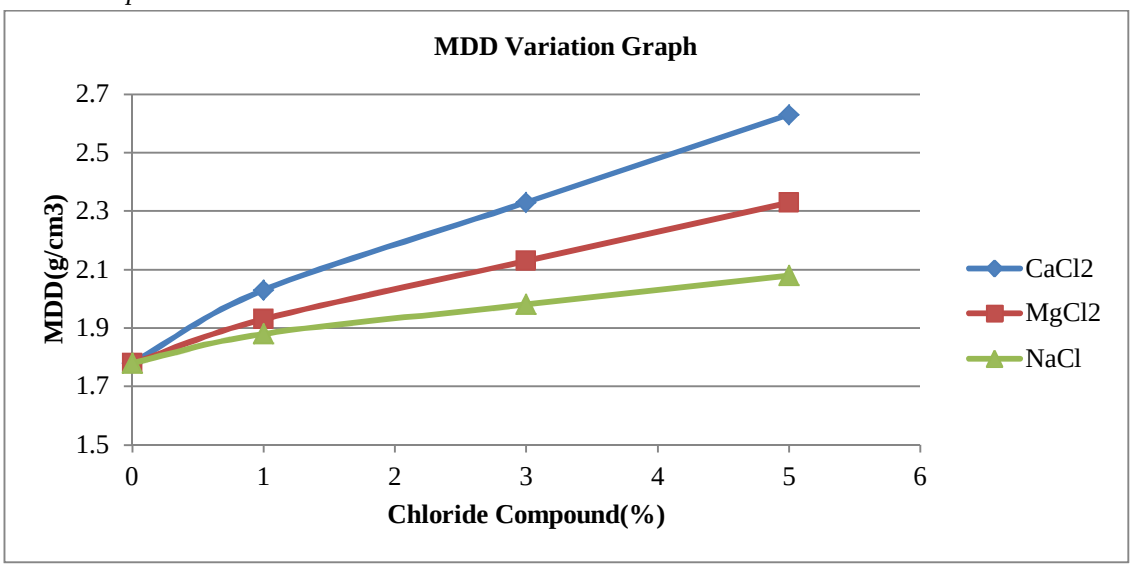

Fig.3. MDD Variation

From the above analysis as we increase the quantity of different Chloride compound ($CaCl_2$, $MgCl_2$ and NaCl) from 1% to 5% there are following changes occurs:-

1) In case of $CaCl_2$ OMC is decreased by 38.23 % and MDD increased by 47.75%
2) In case of $MgCl_2$ OMC is decreased by 29.49% and MDD increased by 30.89%
3) In case of NaCl OMC is decreased by 20.92% and MDD increased by 16.85%

F. Variation in UCS after mixing Chloride Compound with Soil

Table.4. Variation in UCS

Description	Soil	$CaCl_2$			$MgCl_2$			NaCl		
		1%	3%	5%	1%	3%	5%	1%	3%	5%
UCS	1.75	1.95	2.20	2.45	1.85	2.00	2.15	1.80	1.90	2.00

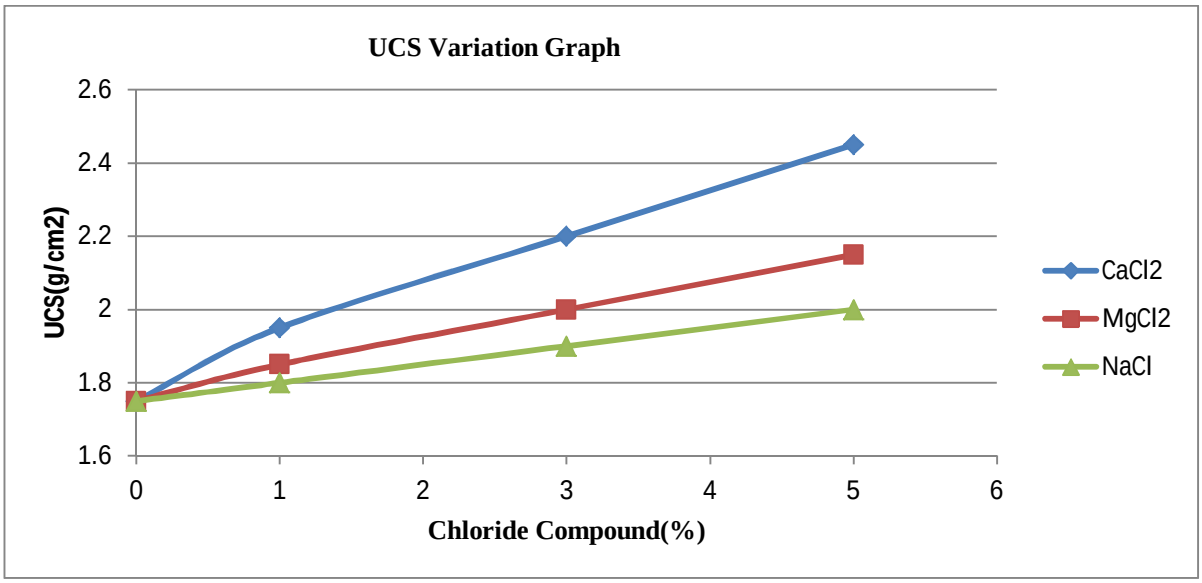

Fig.4. UCS Variation

From the above analysis as we increase the quantity of different Chloride compound ($CaCl_2$,$MgCl_2$ and NaCl) from 1% to 5% there are following changes occurs:-

1) In case of $CaCl_2$ UCS is increased by 40 %
2) In case of $MgCl_2$ UCS is increased by 22.85 %
3) In case of NaCl UCS is increased by 14.28 %

V. CONCLUSION

An extensive experimental analysis has been performed to study the effect of Chloride Compound (i.e. $CaCl_2$, $MgCl_2$ and NaCl) on clay soil after mixing in different proportions. Based on the experimental data collected and analyzed for the soil, soil mixed with Chloride compound at 1%, 3%, and 5% by weight of dry soil. Based on detailed discussions ,the following main conclusions may be drawn as given below:

A. For Native Soil

1) The soil is classified as CH i.e. clay having high plasticity with Plasticity Index and Specific gravity as 26.44% and 2.65 respectively.
2) The OMC ,MDD and Unconfined Compressive strength values are obtained experimentally are 19.12% ,1.780 ,and 1.750 g/cm^2

B. For the Soil Mixed with Calcium Chloride ($CaCl_2$)

1) It is seen that in case of 1% $CaCl_2$, Plasticity Index, and OMC, is decreased from 26.44% and 19.12% respectively to 24.92%, and 17.01% respectively. While the MDD and Unconfined compressive strength increase from 1.780 gm/cc and 1.750 g/cm^2 respectively to 2.03 g/cc and 1.95 g/cm^2 respectively.

2) In case of 3% $CaCl_2$, Plasticity Index, and OMC, is decreased from 26.44% , and 19.12% respectively to 23.45%, and 14.41% respectively. While the MDD and Unconfined compressive strength increase from 1.780 g/cc and 1.750 g/cm^2 respectively to 2.33 g/cc and 2.20 g/cm^2 respectively.

3) In case of 5% $CaCl_2$, Plasticity Index, and OMC, is decreased from 26.44%, and 19.12% respectively to 21.93%, and 11.81% respectively. While the MDD and Unconfined compressive strength increase from 1.780 g/cc and 1.750 g/cm^2 respectively to 2.63 g/cc and 2.45 g/cm^2 respectively.

C. For the Soil mixed with Magnesium Chloride ($MgCl_2$)

1) It is seen that in case of 1% $MgCl_2$, Plasticity Index, OMC, and Free swell index is decreased from 26.44%, 19.12% and 55.02% respectively to 25.44%, 17.62% and 53.04% respectively. While the MDD and Unconfined compressive strength increase from 1.780 g/cc and 1.750 g/cm^2 respectively to 1.93 g/cc and 1.85g/cm^2 respectively.

2) In case of 3% $MgCl_2$, Plasticity Index, OMC, and Free swell index is decreased from 26.44%, 19.12% and 55.02% respectively to 24.44%, 15.51% and 50.54% respectively. While the MDD and Unconfined compressive strength increase from 1.780 g/cc and 1.750 g/cm^2 respectively to 2.13 g/cc and 2.00 g/cm^2 respectively.

3) In case of 5% $MgCl_2$, Plasticity Index, OMC, and Free swell index is decreased from 26.44%, 19.12% and 55.02% respectively to 23.44%, 13.48% and 48.04% respectively. While the MDD and Unconfined compressive strength increase from 1.780 g/cc and 1.750 g/cm^2 respectively to 2.33 g/cc and 2.15 g/cm^2 respectively.

D. For the Soil mixed with Sodium Chloride (NaCl)

1) It is seen that in case of 1% NaCl, Plasticity Index, and OMC, is decreased from 26.44%, and 19.12% respectively to 25.94%, and 18.12% respectively. While the MDD and Unconfined compressive strength increase from 1.780 g/cc and 1.750g/cm^2 respectively to 1.88 g/cc and 1.80 g/cm^2 respectively.

2) In case of 3% NaCl, Plasticity Index, and OMC, is decreased from 26.44%, and 19.12% respectively to 25.44%, and 16.62% respectively. While the MDD and Unconfined compressive strength increase from 1.780 g/cc and 1.750 g/cm^2 respectively to 1.93 g/cc and 1.90 g/cm^2 respectively.

3) In case of 5% NaCl, Plasticity Index, and OMC, is decreased from 26.44% and 19.12% respectively to 24.94%, and 15.12% respectively. While the MDD and Unconfined compressive strength increase from 1.780 g/cc and 1.750 g/cm^2 respectively to 2.03 g/cc and 2.00 g/cm^2 respectively.

- The purpose of this study was to ascertain how three chloride compounds $CaCl_2$, $MgCl_2$, and NaCl, added to clay soil would affect its characteristics. The soil underwent tests to determine its shear strength, dry unit weight, and shear limit for liquid and plastic. The liquid limit, plastic limit, and plasticity index of the soil were all reduced by the addition of each individual chloride compound. With the percentage of salts increasing, the Maximum dry density increases and the Optimum moisture content decreases. Compounds containing chloride were added to the soil, increasing its compressive strength. Strengthening the soil and enhancing its other qualities may be helped by this.
- On the basis of results among all the three Chloride compound $CaCl_2$ gives the best result to reduce the Plasticity Index, and OMC while increases MDD and Unconfined compressive strength of the clay soil.
- There are many regions in India such as Plateau of Maharashtra, Plateau of Malwa (MP), Uttar Pradesh, Chhattisgarh and extended in South-East direction which contain 20% area of total land area as Expansive Soil (Clay Soil). On the basis of above result we can improve the engineering properties of clay soil which will help us to prevent sudden settlement of structural project.

VI. FUTURE SCOPE

Based on this study, the work may be extended keeping the following points in considerations:

1) To study the effect of Chloride compound on the characteristics of sandy soil.

2) To investigate potential expansive soil settlement before construction in order to reduce differential settlement.

3) To stabilize the clay soil by mixing with Chloride compound and other admixture it may be either chemicals or any waste materials.

4) We can investigate the clay soil existing in the sub grade of roads to reduce the water retention capacity of the soil.

5) To investigate the impact of Chloride compound on stabilization of the clay soil of sloppy areas which will help to increase the shearing strength and provide stability in soil nailing process.

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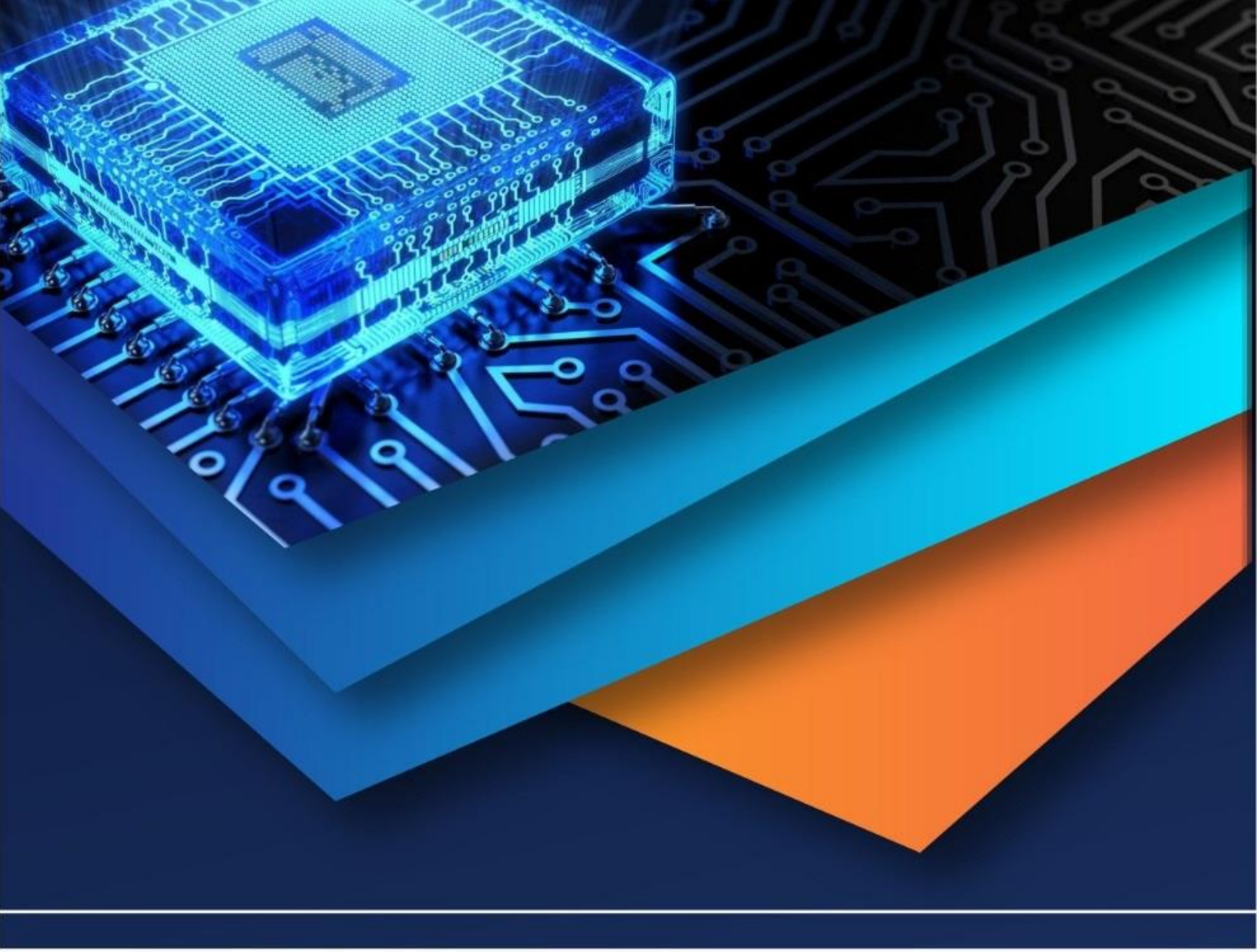

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