IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 22, Issue 2 Ser. 3 (Mar. – Apr. 2025), PP 50-54
www.iosrjournals.org

A Laboratory Study On The Effect Of Concentration-Based Magnesium Chloride Compounds On Expansive Soil For Foundation Applications

A Surya Manikantha, V Eswara Rao, G.Bhargava, I Dileep Kumar, C Niteesh Kumar Reddy, A Lakshmana Rao
(Assistant Professor, Department Of Civil Engineering, Sir C R Reedy College Of Engineering, India)
(UG Student, Department Of Civil Engineering, Sir C R Reedy College Of Engineering, India)

Abstract:
Black Cotton Soils are known for their high swelling and shrinkage potential due to moisture fluctuations, resulting in severe volumetric changes. These behaviours lead to excessive settlement and structural instability, posing significant challenges in construction over such soils. Black cotton soils need to be improved to make them suitable for construction. Soil stabilization is the process employed to improve these soils' characteristics is called soil stabilization. Chemical stabilization, which entails adding chemicals to increase the soil's strength. To mitigate these issues, this study explores the effectiveness of chemical stabilization using sodium hydroxide (NaOH) and magnesium chloride ($MgCl_2$) as soil stabilizers. Unconfined Compressive Strength (UCS)were conducted on Black Cotton Soil treated with different concentrations of these chemical agents. The study on 1.5% of NaOH and $MgCl_2$ with the different molarities (2M,4M,6M,8M &10M), aiming to evaluate the improvement in mechanical strength and overall geotechnical behaviour of the soil. Results indicate that increasing the salt concentration enhances the Unconfined Compressive Strength (UCS), significant improvement in soil stability. This highlights the potential of chemical stabilization as a reliable technique for improving expansive soils for engineering applications.
Key Word: *Expansive soil, magnesium chloride, molarity, unconfined compressive strength.*

Date of Submission: 11-04-2025 Date of Acceptance: 21-04-2025

I. Introduction

Expansive soils, known for their high shrink-swell potential, present significant challenges to the stability of construction and infrastructure. To address these issues, the use of magnesium chloride ($MgCl_2$) compounds has gained attention due to their ability to modify the physicochemical properties of the soil. This study explores the effect of different concentrations of magnesium chloride compounds on the behavior of expansive soils, focusing on changes in swelling, shrinkage, and strength characteristics. By determining the optimal concentration for soil stabilization, the research aims to provide valuable insights into improving soil performance. The findings have the potential to offer cost-effective and sustainable solutions for managing expansive soils in civil engineering applications. It works by altering the soil's moisture content and ionic composition, which can lead to a reduction in the soil's tendency to swell and shrink[1]. The paper explores an innovative approach to lime stabilization by facilitating in situ precipitation of lime through the sequential permeation of calcium chloride ($CaCl_2$) and sodium hydroxide (NaOH) solutions[2]. Physical adsorption involves van der Waals forces, while chemical adsorption involves stronger covalent bonds[3]. Lime improves soil workability and reduces swelling by saturating clay particles with calcium ions, while cement forms cementing compounds that enhance soil strength and reduce permeability[4]. he improvement in strength is primarily due to the reduction in moisture content and the formation of cementitious compounds[5]. By comparing the individual effects of lime, cement, and fly ash, the literature review emphasizes that a combination of additives is often more effective in improving soil properties, balancing quick strength gain with improved workability and reduced swelling[6]. his rapid reaction implies that the chemical stabilization process using $MgCl_2$ is both effective and time-efficient, likely providing considerable benefits in practical engineering applications[7]. The treatment led to the formation of new crystalline compounds, specifically magnesium aluminate hydrate (M-A-H), which acted like a binder to hold the soil particles together effectively[8]. This study investigates the influence of different concentrations of magnesium chloride compounds on the geotechnical properties of expansive soils through a series of laboratory tests. The primary objective is to assess the reduction in swell potential, improvement in strength characteristics, and changes in soil structure induced by magnesium chloride treatments. The findings from this research aim to provide valuable insights for engineers and geotechnical professionals to enhance the performance and longevity of foundations constructed on expansive soils.

II. Material And Methods

The experimental methodology for evaluating the effect of varying molar concentrations of magnesium chloride ($MgCl_2$) on the properties of expansive soils involves a systematic approach, including soil sampling, sample preparation, treatment with $MgCl_2$ solutions, and a series of laboratory tests to assess changes in soil behaviour.

Expansive soil: Expansive soils in India are popularly known as Black cotton soils, the collected soil was dried and pulverized into the required sizes and tested for properties like gradation, compaction, strength as per IS2720 and the results are shown in table-1.

Table 1-*Geotechnical properties of Black cotton soil*

S.No	Geotechnical Properties		values
1	Gravel (%)		0
2	Sand (%)		6
3	Fines (%)	Silt (%)	48
		Clay (%)	46
4	Liquid Limit (%)		68
5	Plastic Limit (%)		32
6	Plasticity Index (IP)		36
7	IS Classification		CH
8	Optimum moisture content (OMC) (%)		27
9	Maximum dry density (MDD) (g/cc)		1.42
10	California bearing ratio (%) (Soaked)		1.2
11	Cohesion (kPa)		117

The soil is highly plastic and expansive, posing challenges for foundations due to poor drainage and high swelling. It contains 48% silt and 46% clay, with a liquid limit of 68% and a plasticity index of 36%, classifying it as **CH** (high plasticity clay). The soil has high moisture content (27%) but low dry density (1.42 g/cc) and a poor CBR value (1.2%), indicating weak load-bearing capacity. High cohesion (12 t/m²) adds stability when dry but increases swelling when wet. Stabilization with lime, cement, or magnesium chloride is essential to enhance its properties for foundation applications.

Preparation of Magnesium Chloride Solutions.
Solution Concentrations: Magnesium chloride ($MgCl_2$) is prepared in varying molar concentrations (e.g., 2,4,6,8 and 10M) by dissolving the required amount of $MgCl_2$ in distilled water.
Solution Application: The $MgCl_2$ solutions are thoroughly mixed with the soil samples at the predetermined concentrations to ensure uniform distribution**.**

III. Results And Discussions

Effect of magnesium chloride on expansive soil:

To study the effect of magnesium chloride on expansive soil, various concentrations i.e. 2,4,6,8 and 10M with 1.5% of dry weight of soil were added and effectively mixed and tested for characteristics like plasticity, compaction and strength l as per IS:2720 results are shown in table-2.

Table -2 *Variation of Geotechnical properties with Magnesium chloride*

S.NO	$Mgcl_2$(%)	Molarity Concentration of $mgcl_2$	W_L (%)	P_L (%)	PI (%)	OMC (%)	MDD (g/cc)	UCC (kPa)
1	0	-	68	32	36	27	1.42	136.80
2	1.5	2M	62	29	33	26.2	1.48	162.30
3	1.5	4M	54	23	31	25.4	1.54	191.72
4	1.5	6M	48	20	28	23	1.63	233.40
5	1.5	8M	44	18	26	20	1.69	338.82

The table.2 presents the influence of magnesium chloride ($MgCl_2$) treatment on the Atterberg limits of soil. A consistent $MgCl_2$ content of 1.5% is used, while the molarity is varied from 2M to 10M, along with a control sample with no $MgCl_2$ for baseline comparison.

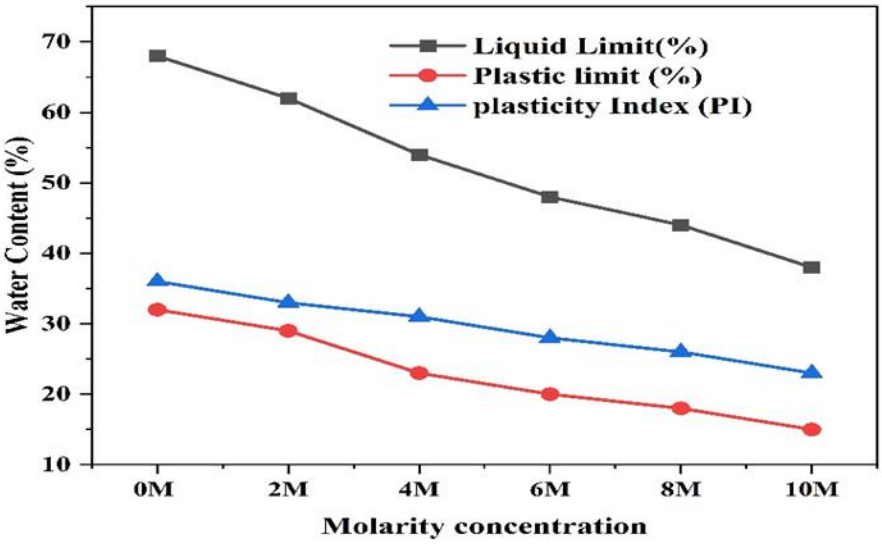

Fig.1. Effect of Molarity Concentration on Atterberg's Limits

It is observed that the Liquid Limit (WL) shows a steady decrease from 68% in the untreated sample to 38% at 10M $MgCl_2$. Similarly, the Plastic Limit (PL) also declines from 32% to 15% over the same molarity range. This reduction in both limits indicates a significant alteration in the soil's consistency, likely due to cation exchange and flocculation effects introduced by Mg^{2+} ions, which lead to a reduction in the soil's ability to retain water.The Plasticity Index (PI), which is the difference between WL and PL, also exhibits a downward trend from 36% to 23%, reflecting a decrease in the plastic behavior of the soil with increasing $MgCl_2$ molarity. This reduction in PI suggests improved soil stability and decreased potential for volumetric changes upon moisture fluctuations, which is advantageous in geotechnical applications.Overall, the treatment with $MgCl_2$ is effective in reducing the plasticity characteristics of the soil. The decreasing trend in Atterberg limits indicates that higher molarity concentrations of $MgCl_2$ promote soil stabilization by reducing its water sensitivity and plastic nature.

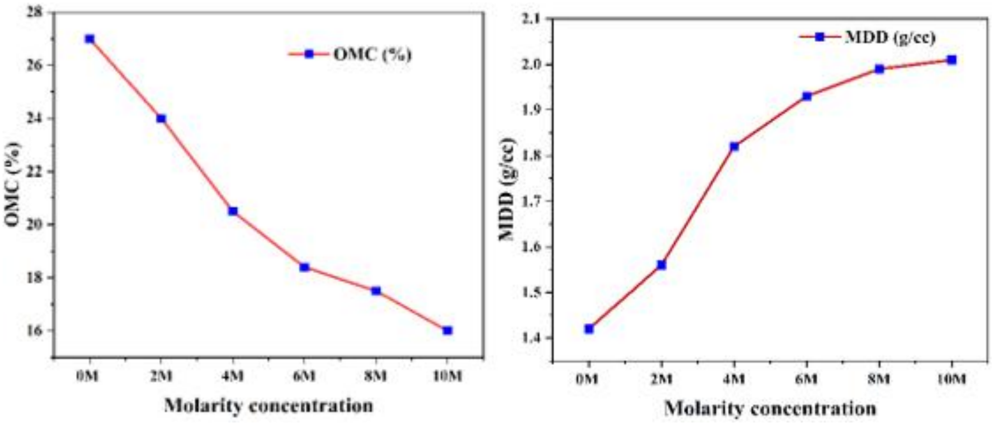

Fig.2. Effect of Molarity Concentration on Compaction Characteristics

The data illustrates the effect of $MgCl_2$ treatment on the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of soil. As the molarity of $MgCl_2$ increases from 2M to 10M, there is a consistent decrease in OMC and a corresponding increase in MDD. Initially, the untreated soil exhibits an OMC of 27% and an MDD of 1.42 g/cc. With the addition of 1.5% $MgCl_2$ at 2M molarity, OMC drops slightly to 26.2% while MDD increases to 1.48 g/cc. This trend continues progressively, with OMC reducing to 17.5% and MDD rising to 1.72 g/cc at the highest molarity of 10M. The decrease in OMC suggests that treated soil requires less moisture to reach maximum compaction, likely due to improved particle flocculation and reduced water retention capacity caused by the presence of divalent Mg^{2+} ions. Meanwhile, the increase in MDD reflects a denser soil structure, possibly resulting from better particle rearrangement and bonding due to chemical stabilization. These findings indicate that $MgCl_2$ treatment enhances the compaction characteristics of the soil, making it more suitable for use in construction and engineering applications where higher strength and lower moisture content are desirable.

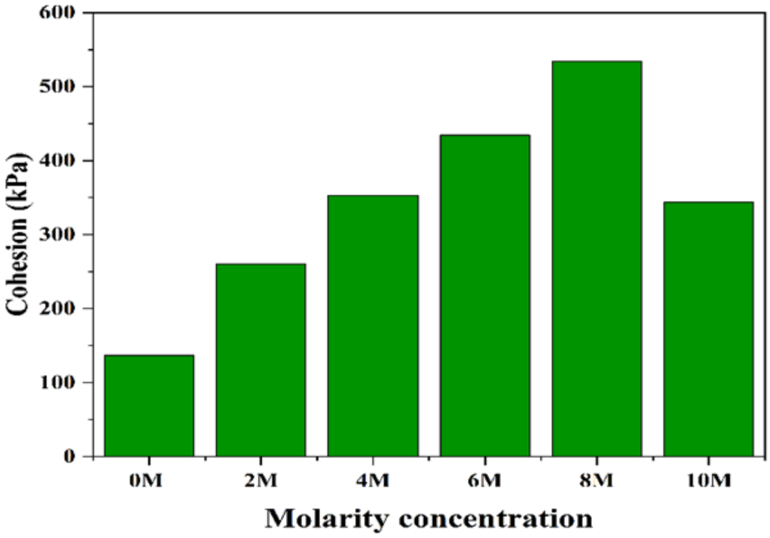

Fig.3. Effect of Molarity Concentration on Shear Parameter of Cohesion

The table.2 illustrates the influence of varying molar concentrations of $MgCl_2$ on the Unconfined Compressive Strength (UCS) of soil. Initially, the untreated soil exhibits a UCS of 136.80 kPa. With the addition of 1.5% $MgCl_2$ at 2M molarity, the UCS increases to 162.30 kPa, indicating an improvement in the soil's strength due to the stabilizing effect of Mg^{2+} ions. This trend continues with higher molarity levels, reaching 191.72 kPa at 4M and 233.40 kPa at 6M, reflecting the enhanced bonding between soil particles and a more compacted soil matrix. The UCS peaks at 338.82 kPa with 8M $MgCl_2$, representing the highest strength gain in the series. This suggests that 8M is the optimum molarity for maximum soil stabilization using $MgCl_2$ under the tested conditions. However, at 10M concentration, the UCS decreases to 260.86 kPa, indicating a reduction in strength. This drop could be attributed to excessive salt content leading to potential leaching, over-flocculation, or a weakening of the soil structure beyond the optimal stabilization point.Overall, the UCS data confirms that $MgCl_2$ significantly enhances the strength of soil, with the most effective stabilization observed at 8M molarity. Beyond this concentration, the benefits begin to diminish, suggesting the need for careful optimization in practical applications.

IV. Conclusions

1. The Atterberg limits decreased notably with increasing $MgCl_2$ molarity. The Liquid Limit (WL) dropped from 68% (untreated) to 38% at 10M, and the Plastic Limit (PL) declined from 32% to 15%. Consequently, the Plasticity Index (PI) reduced from 36% to 23%, indicating a substantial decrease in soil plasticity and improved stability due to the flocculating effect of Mg^{2+} ions.
2. The Optimum Moisture Content (OMC) decreased from 27% (untreated) to 17.5% at 10M, while the Maximum Dry Density (MDD) increased from 1.42 g/cc to 1.72 g/cc. This demonstrates that $MgCl_2$-treated soils require less water for compaction and attain a denser structure, which is beneficial for load-bearing applications.
3. The Unconfined Compressive Strength (UCS) improved significantly with $MgCl_2$ treatment, increasing from 136.80 kPa (untreated) to a maximum of 338.82 kPa at 8M. This indicates a 2.5 times increase in strength, highlighting the effectiveness of $MgCl_2$ in enhancing the load resistance of the soil.
4. Although UCS continued to rise up to 8M, it dropped to 260.86 kPa at 10M, suggesting that 8M $MgCl_2$ provides the most effective stabilization. Beyond this molarity, excessive salt content may reduce strength due to over-flocculation or leaching effects.
5. The consistent improvements in PI (36% to 23%), OMC (27% to 17.5%), MDD (1.42 g/cc to 1.72 g/cc), and UCS (136.80 kPa to 338.82 kPa) demonstrate that $MgCl_2$ at 1.5% content, particularly at 8M molarity, is highly effective for stabilizing soil. However, careful control of molarity is crucial to avoid diminishing returns or structural compromise at higher concentrations.

References

[1] B. R. Phanikumar And S. Suri, "Chemical Amelioration Of Expansive Soils," Jan. 2014, Doi: 10.5281/Zenodo.1336352.

[2] T. Thyagaraj, S. M. Rao, P. Sai Suresh, And U. Salini, "Laboratory Studies On Stabilization Of An Expansive Soil By Lime Precipitation Technique," J. Mater. Civ. Eng., Vol. 24, No. 8, Pp. 1067–1075, Aug. 2012, Doi: 10.1061/(Asce)Mt.1943-5533.0000483.

[3] A. R. Estabragh, E. Afsari, A. A. Javadi, And M. Babalar, "Effect Of Two Organic Chemical Fluids On The Mechanical Properties Of An Expansive Clay Soil," Journal Of Testing And Evaluation, Vol. 48, No. 5, Pp. 3501–3514, Sep. 2020, Doi: 10.1520/Jte20170623.

[4] E. Mutaz, M. A. Shamrani, A. J. Puppala, And M. A. Dafalla, "Evaluation Of Chemical Stabilization Of A Highly Expansive Clayey Soil," Transportation Research Record: Journal Of The Transportation Research Board, Vol. 2204, No. 1, Pp. 148–157, Jan. 2011, Doi: 10.3141/2204-19.

[5] Y. Tang, N. Wang, F. Xu, D. Teng, And X. Cui, "Electrokinetic Stabilization Of Marine Clayey Soil Using Magnesium Chloride Solution: A Green Soil Stabilizer," Marine Georesources & Geotechnology, Vol. 40, No. 2, Pp. 248–254, Feb. 2022, Doi: 10.1080/1064119x.2021.1895384.

[6] D. Barman And S. K. Dash, "Stabilization Of Expansive Soils Using Chemical Additives: A Review," Journal Of Rock Mechanics And Geotechnical Engineering, Vol. 14, No. 4, Pp. 1319–1342, Aug. 2022, Doi: 10.1016/J.Jrmge.2022.02.011.

[7] W. H. Wan Hassan, A. S. A. Rashid, N. Latifi, S. Horpibulsuk, And S. Borhamdin, "Strength And Morphological Characteristics Of Organic Soil Stabilized With Magnesium Chloride," Qjegh, Vol. 50, No. 4, Pp. 454–459, Nov. 2017, Doi: 10.1144/Qjegh2016-124.

[8] N. Latifi, A. S. A. Rashid, A. Marto, And M. M. Tahir, "Effect Of Magnesium Chloride Solution On The Physico-Chemical Characteristics Of Tropical Peat," Environ Earth Sci, Vol. 75, No. 3, P. 220, Feb. 2016, Doi: 10.1007/S12665-015-4788-6.