Impact of Calcium Chloride on Mechanical Characteristics of Black Cotton Soil

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Abstract. Black cotton soils are very expansive in nature. It is well known that they exhibit swelling nature when water is being dried out. These soils possess several foundation and stability problems of Civil Engineering structures constructed over them. Hence there is a need to stabilize the expansive soil. From the literature it was observed that chemical stabilization is very effective in stabilizing the expansive soils and has several advantages when compared to other Stabilizing methods.

In this paper the authors concentrated on the impact of calcium chloride on the strength properties of the black cotton soil. This research discusses the effects of calcium chloride on the strength of black cotton soil. The soil used belongs to the "CH" group according to IS soil classification, and its DFSI is 115%, indicating a high degree of expansive nature. It was discovered that the strength of the treated soil increases with curing time while decreasing as the pore fluid content moves from the dry side of the optimum moisture content to the wet side of the optimum moisture content, regardless of the calcium chloride percentage concentration. After extensive laboratory research it was reported that stabilization of Black cotton soil with calcium chloride improves the strength characteristics.

Keywords: Black Cotton soil, Calcium Chloride, Strength properties, Differential Free Swell Index labelling.

1 Introduction

Soils located in the vicinity of industrial units are subjected to deterioration of their basic, as well as mechanical properties which can also be brought about by pollution resulting from the deposition of industrial wastes. The most notable sources of top soil and sub soil polluted condition have been industrial wastes, which have largely been uncollected, and also chemical spills associated with the industrial processes. In the event that industrial effluents infiltrate the soil, they affect the ability to utilize the soil as well as the durability of the structures it is meant to support.

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It is nowadays well known that industrial pollution has negative effects on the properties of land – particularly in relation to the more modern production plants. The inappropriate management of industrial waste and the inadvertent discharge of chemicals can cause substantial degradation of both top and subsurface soils and can negatively influence their mechanical and physical properties. In a way, this paper attempts to investigate how such pollution can have a wider effect.However, this work will concentrate on the strength characteristics,treated with calcium chloride on the Black Cotton Soils. In most cases of industrial activity, the soil tends to be polluted with harmful agents, hence, compromising its structure. [1] Documented severe destruction to the pavements and floors as well as the foundations of a light industrial strectures in a fertilizer plant located in Kerala, India which accentuates the danger of industrial waste not being properly managed. Likewise, [2] reported severe damages in Calgary, Canada caused by variable movements of the foundation of the pump and phosphoric acid storage tank which resulted in structural damage. These cases demonstrate the essential importance of assessment and control of the ecological consequences of industrial activity.

The incident in Tema, Ghana, [3] serves as another poignant example of the dangers posed by industrial spills. A leak of a highly concentrated caustic soda solution from fractured pipes caused significant structural damage and localized subsidence in a light industrial building. Such cases underscore the importance of proactive ground monitoring and remediation strategies, emphasizing that preventative measures should be implemented before the ground experiences complete failure. Black Cotton Soils, also known as Regur soils, are characterized by their high shrink-swell potential due to their clayey composition. These soils are sensitive to environmental changes, including variations in moisture content and temperature. Their physical properties can be significantly affected by industrial pollution, leading to alterations in their load-bearing capacity and overall stability.

Considering the problems posed by the Black Cotton Soils, this study investigates the role of calcium chloride ($CaCl_2$) in improving the agricultural soils. Calcium chloride is commonly used for modification of clayey soils due to increase in strength and decrease in plasticity properties. It has been established that the use of $CaCl_2$ helps in enhancing the load bearing index of expansive soils to a significant value, making it productive for reversing the negative effects of bioaccumulated soil pollutants. The situation prompts for organized monitoring and remediation activities such as those caused by expansion of industrial undertakings and the accompanying problem of soil pollution. The application of stabilizing agents like calcium chloride appears to provide a fertile ground for improvement of the Black Cotton Soils. Future researches need to consider issues of the predicted life time of such treatments and its influence on soil sustainability. The present study highlights the need for rapid on site investigation of the ground and the possibilities of chemical remedies for acute problems posed by industrialization to the more delicate soils like the Black Cotton Soils.

The distinctive characteristic of black cotton soils is their excellent shrink swell capacity thereby making them easily affected by environmental factors, changes such as, stress levels, pore water chemistry, depth of groundwater table and temperature.

Thus, this study seeks to explore the effects of calcium chloride on the mechanical characteristics of black cotton soils.

2 Experimental Investigations

2.1 Materials Used

Soil: The material used in this research has been obtained from the Auto Nagar area of Tirupati, which has a lot of clayey soils. The trembling efficient index for this type of soil is 115 % Differential free swell, which indicates a tendency for considerable chauffeuring as water content is modified. When subject to volume change conditions, the unit swelling strain is recorded as 139kN/m². Classification of soil based on casagrande methods classified these soils into class CH (high plasticity clay) [4] according to when was first published known as IS classification 1970 standards. The characteristics of the soil are presented in Table 1.

Table 1. Soil Properties

S.No.	Properties of the soil	Details
1	Distribution of Grain Size	
	a) Gravel (%)	0
	b) Sand (%)	6.5
	c) Silt+Clay (%)	93.5
2	Atterberg Limits	
	a) Liquid Limit (%)	91
	b) Plastic Limit (%)	22
	c) Plasticity Index (%)	64
3	Compaction Characteristics	
	a) Maximum dry unit weight (kN/m^2)	17.2
	b) Optimum moisture content (OMC) (%)	24.5
4	Unconfined compressive strength at OMC (KN/m^2)	118
5	Specific gravity	2.73
6	pH value	8.25
7	Swelling characteristics	
	a) Differential free swell index (%)	115
	b) Swelling pressure (under no-volume-chance condition (kN/m^2)	139

Calcium Chloride: Calcium chloride ($CaCl_2$) – a white colour crystalline solid as well as a hygroscopic powder is highly hygroscopic and has a tendency to absorb nearest moisture in its environment. Being deliquescent, it assists in minimization of moisture loss from soils thereby providing stability as well as improving mechanical properties of the soils. Calcium chloride is also widely employed in various industries like:

- **Construction:** as a deicer and also in cement manufacturing.
- **Food processing:** as a preservative and an agent responsible for firming.
- **Petrochemicals:** used as a drying agent.
- **Refrigerants:** in systems where moisture is required in control.

Table 2 present its chemical composition.

Table 2. Compound organization of calcium chloride

S.No	Contents	Details
1	Assay	99.054
2	Fluoride (F)	0.013
3	Sulphate (SO4)	0.012
4	Heavy metals (As pb)	0.0025
5	Aluminum (Al)	0.0001
6	Arsenic (As)	0.0002
7	Barium (Ba)	0.12
8	Iron(Fe)	0.005
9	Zinc(Zc)	0.003
10	Magnesium+Alkaline metals	0.4
11	Substances precipitated by ammonia (al.Fe.PO4)	0.36

2.2 Soil Preparation

To begin with, moisture was reduced by air-drying the soil collected in the samplers. In order to make the sample as homogeneous as possible, small pebbles, stones, or organic matter were picked up by hand and removed. After which, a soil mass was pulverized to a suitable fineness, and a 4.75 mm sieve was used to screen the coarse fragments. This procedure made it possible to make the soil appropriate for testing and to make it possible for the soil to be obtained in a uniform manner. The treated soil was placed in sealed containers in order to protect it from moisture, which enabled the soil to remain uncontaminated before any contamination occurred.

Procedure for Contamination: Different concentrated calcium chloride solutions were used to contaminate the soil samples. Calcium chloride powder was dissolved in distilled water to make it different options with concentrations of 0%, 2.5%, 5%, 7.5%, 10%, 12.5%, 15% and 20%. The preparation procedure consisted of:

1. **Dissolution:** The powder form of calcium chloride was acquired in specific amounts for different concentrations and dissolved in a defined amount of distilled water.
2. **Mixing:** The soil sample was evenly mixed with the calcium chloride solution and leave it for some time to guarantee the chemical will be distributed evenly in the soil.
3. **Curing:** The mixed samples were allowed to cure for a certain specified time, which was done to allow for chemical reaction and stabilization of the soil properties.

2.3 Testing and Analysis

The following examinations were conducted on the polluted soils to investigate the influence of calcium chloride:

1. **Compaction Tests:** This test was performed to establish the maximum dry density and optimum moisture content (OMC) for the soils [5].
2. **Unconfined Compressive Strength (UCS) Tests:** This test was performed to determine the strength properties of the soils contaminated with different concentrations of calcium chloride [6].
3. **Swelling Tests:** This test was performed to determine the swelling potential of the soils.

3 Results and Discussion

Figure 1 depicts the variation in Unconfined Compressive Strength (UCS) of contaminated soil with varying calcium chloride concentrations across curing periods of 0, 1, 3, 7, and 15 days. For comparison, the UCS of uncontaminated soil is marked as a reference point in the figure. The highest curve corresponds to the 15-day curing duration, followed by the curves for 7 days, 3 days, 1 day, and 0 days. This trend indicates that the UCS of contaminated soil increases with longer curing times, regardless of the concentration of calcium chloride, except at the highest concentration of 20.0%. Notably, specimens treated with a concentration of 15.0% calcium chloride and cured for 15 days exhibited the maximum strength, highlighting the effectiveness of calcium chloride in improving the engineering properties of expansive clay soils.

The observed rise in UCS with curing time can be attributable to the continuous chemical reactions between the calcium chloride and the soil particles, which improve particle bonding and limit flexibility[7]. Additionally, longer curing times allow for better hydration and compaction of the soil matrix, resulting in improved structural integrity [8].

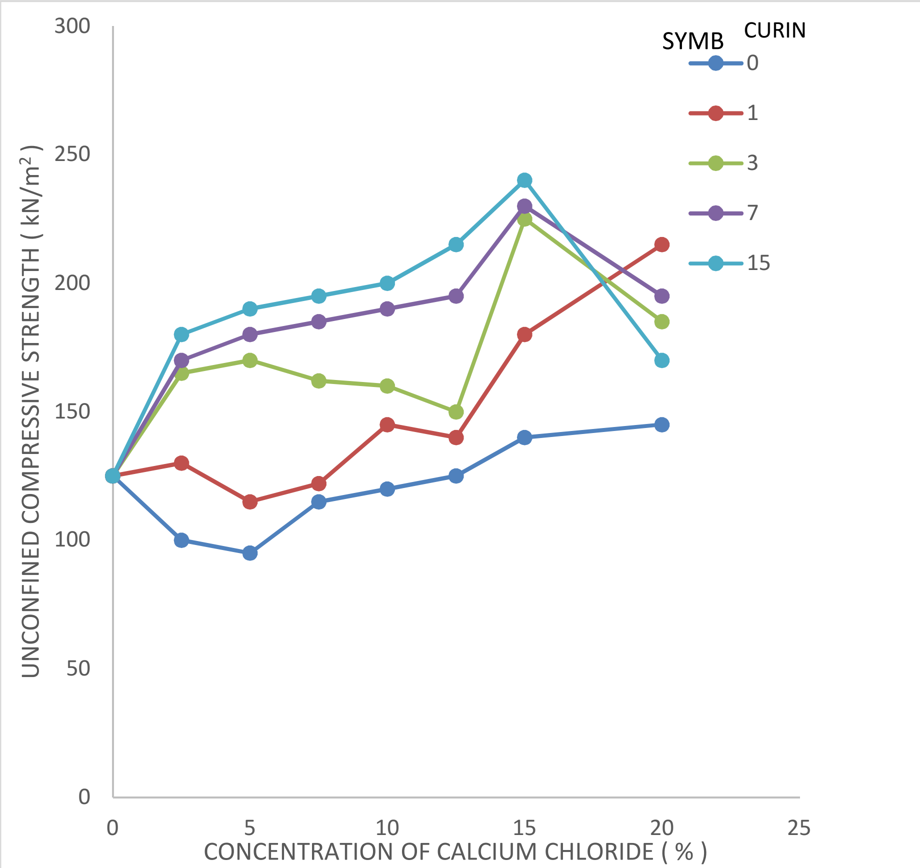

Fig. 1. Unconfined compressive strength varies with calcium chloride concentration throughout different curing durations

To aid comprehension, a parameter known as the pore fluid content ratio, or PCR, is defined. This means that the PCR expresses the ratio between the contaminated soil's pore fluid content and its optimal pore fluid content.Such a parameter facilitates a better understanding of how different moisture contents affect the strength characteristics of the soil.

Fig. 2 displays the data relating UCS and the amount of calcium chloride over different concentrations: for the dry side and that for the wet side of OPC. Optimum pore fluid content, which is applicable to UCS variations, is plotted in the same graph for comparison. In the figure, the PCR 0.90, followed by 0.95, 1.00, 1.05, 1.10. The observations show that even with the change in the concentration of calcium chloride, the strength measured on the dry side of optimum moisture content is always greater than that at optimum pore fluid content. This is due to a better compacted structure and a lower pore water pressure in a drier material condition leading to increased effective stress in the soil [9].

Conversely, the strength on the wet side of optimum moisture content is lower than that at optimum pore fluid content across all concentrations of calcium chloride. This decline in strength can be explained by the excess pore water, which reduces the effective stress and contributes to a more plastic behavior of the soil [10].

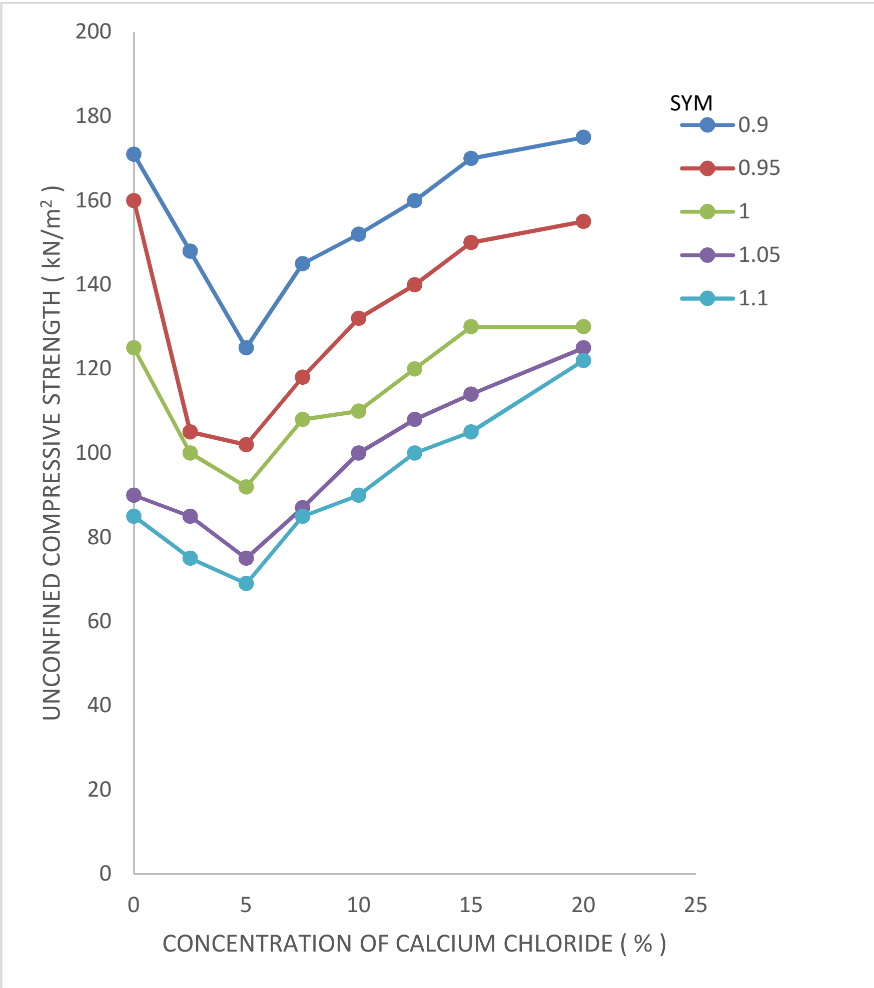

Fig. 2. Unconfined compressive strength varies with calcium chloride concentration for various pore fluid content ratios

4 Conclusions

Stabilization of black cotton soil with calcium chloride has demonstrated significant improvements in the soil's load-bearing and structural properties. Over varying curing periods and calcium chloride concentrations, the unconfined compressive strength (UCS) showed a clear increase, with the most notable enhancements at 15% calcium chloride concentration and a curing period of 15 days. These findings align with prior research that underscores the efficacy of calcium chloride in improving soil integrity [7]. The data suggest that calcium chloride can mitigate the expansive nature of black cotton soils by reducing plasticity and enhancing particle bonding, which strengthens the soil matrix.

However, results also indicate that there is an optimal concentration threshold (15% in this study) beyond which additional calcium chloride does not significantly enhance strength and may even reduce it. This observation is consistent with the theory of diminishing returns in soil treatment, where excessive additive concentration can lead to chemical imbalances and reduced cohesion [9].

The pore fluid content ratio (PCR) analyses revealed that soils on the dry side of optimum moisture content consistently exhibited higher UCS than those on the wet side, a pattern supported by studies on effective stress principles in expansive soils [10]. This suggests that managing moisture levels is crucial for achieving optimal stabilization results with calcium chloride.

Future research should explore long-term environmental impacts of calcium chloride in soil stabilization and its performance under various climate conditions. Additionally, comparing calcium chloride with alternative stabilizing agents in a controlled study could further establish its effectiveness and sustainability for infrastructure projects on expansive soils.

In conclusion, calcium chloride is a viable and efficient agent for improving the strength characteristics of black cotton soils, offering a promising solution to the challenges posed by expansive soils in construction. The insights from this study can guide civil engineering applications and policy-making in soil stabilization, emphasizing the importance of careful concentration management and moisture control for optimal results.

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