Interpretation of Geotechnical Properties of Lime Treated Soils with Additives

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Abstract— Expansive soils are found in the arid and semi-arid regions of the world and are in abundance where the annual evaporation exceeds the precipitation. Expansive soils experience large volume changes on exposure to climates with alternate wet and dry seasons. These soils shrink on drying with accompanied cracking. If rewetted subsequent to drying, swelling occurs with enclosure of fissures. Expansive soils exhibits high plasticity characteristics, low strength properties and high swell shrink characteristics. The alternate swell shrink seasons cause distress to the structure or the pavement constructed on them. Maintenance and repair cost of the distressed structure or pavement may be quite high. New methods continue to be researched to increase the strength properties and to reduce the swell behavior of expansive soils. Many researchers have tried new stabilizers like natural fabricated and byproduct materials, gels, polymers, silica fumes etc. and there use as stabilizers for the modification of clayey soils and from literature available the results are encouraging. Hence, in this present work, lime and other additives such as NaCl, NaOH and Mine Tailings has been used to stabilize expansive black cotton soils.

Key words: Expansive, plasticity, distressed, silica fumes, Mine Tailings

I. INTRODUCTION

Geotechnical properties of problematic soils such as soft fine-grained and expansive soils are improved by various methods. The problematic soil is removed and replaced by a good quality material or treated using mechanical and/or chemical stabilization. Different methods can be used to improve and treat the geotechnical properties of the problematic soils (such as strength and the stiffness) by treating it in situ. These methods include densifying treatments (such as compaction or preloading), pore water pressure reduction techniques (such as dewatering or electro-osmosis), the bonding of soil particles (by ground freezing, grouting, and chemical stabilization), and use of reinforcing elements (such as geotextiles and stone columns) (William Powrie, 1997). The chemical stabilization of the problematic soils (soft fine-grained and expansive soils) is very important for many of the geotechnical engineering applications such as pavement structures, roadways, building foundations, channel and reservoir linings, irrigation systems, water lines, and sewer lines to avoid the damage due to the settlement of the soft soil or to the swelling action (heave) of the expansive soils. Generally, the concept of stabilization can be dated to 5000 years ago. McDowell (1959) reported that stabilized earth roads were used in ancient Mesopotamia and Egypt, and that the Greek and the Romans used soil-lime mixtures. Kézdi (1979) mentioned that the first experiments on soil stabilization were achieved in the USA with sand/clay mixtures round 1906. In the 20th century, especially in the thirties, the soil stabilization relevant to road construction was applied in Europe. In Germany, Vosteen (1998 & 1999) reported that the use of cement or lime for the stabilization of pavement bases (during the past few decades) was investigated and developed into practical construction procedures. These practical procedures have been improved and covered periodically by the technical standards for road and traffic. Fly ash-soil stabilization for road construction is applied in USA, Japan, Scandinavian countries, and some other countries like India. In Germany, fly ash-soil stabilization for road construction is not applied and there are no German recommendations and regulations for soil stabilization using fly ash.

II. LITERATURE REVIEW

Generally, partially saturated clayey soils having high plasticity are very sensitive to variations in water content and show excessive volume changes. Such soils, when they increase in volume because of an increase in their water contents, are classified as expansive soils. This highly plastic soil may create cracks and damage on the pavements, railways, highway embankments, roadways, building foundations, channel and reservoir linings, irrigation systems, water lines, sewer lines etc (Gromko, 1974, Mowafy, 1985 and Kehew, 1995). Thereafter, highly plastic soil exhibits undesirable engineering properties under load. They have low shear strengths and tendency to lose shear strength further upon wetting or other physical disturbances (Mitchell, 1986). Therefore, this plastic soil is very prone to shear failure due to the constant load over time and considered poor material for foundations (Liu et. al. 2008). High water content, high compressibility and low workability of these soils often caused difficulties in the civil engineering construction projects. The soil which is used for the construction pavement or sub-base should have some specification of geotechnical properties for obtaining required strength against tensile stresses and strains variety. In this study, RHA was used for the improvement of workability, compressibility and compaction characteristics as well as the physical properties of highly plastic clayey soil. In the earlier, cement and lime are the two main materials used for stabilizing soils which is now costly in price due to the sharp increase in the cost of energy since 1970s (Neville, 2000). RHA is the most cost-effective locally available materials act as a binding agent like cement which increases some geotechnical properties as well as stabilization of soil as an alternative option of cement and lime. Disposal of surplus soils at construction sites has become an urgent problem as it is becoming increasingly difficult to secure dumping sites. Therefore, it is necessary to recycle the surplus soils by relatively simple treatment such as chemical stabilization. Lime and cement are the effective admixtures for stabilization. Adding lime or cement to soft clay improves its engineering properties such as index properties, strength and resistance to compressibility. The successful application of lime and lime mixed with waste materials such as fly ash, ark shell ash and foamed waste glass stabilized soft Ariake clay were reported by Nanri and Onitsuka (1996) and Onitsuka and Shen(1998, 2000). The lime and cement stabilized surplus clays are normally utilized as engineering materials for backfill and pavement. The strength development of lime and cement stabilized clay are mainly obtained by formation of cementing products ($CaO\text{-}SiO_3\text{-}H_2O$, $CaO\text{-}Al_2O_3\text{-}H_2O$) that were investigated by x-ray diffraction and scanning electron microscope (SEM) (Kawamura and Diamond 1975 ; Kamon and Nontananandh 1991 and Rajasekaran et al.1997). It is clearly shown that the cementing products cause the strength of stabilized clay to increases. There are many factors such as differences in soil gradation, types of clay minerals, organic matter, pH, Sulphate and etc., (Sherwood 1958, 1962; Moh 1962; Mateos 1964; Thompson 1966 and Miura et al.1988) that significantly influence the ability of clay to react with lime and cement to achieve a strength increase. Ariake clay is a kind of very high sensitive clay that deposited around the coast of the Ariake Bay in Kyushu Island (Nakamura et.al.1985). The clay near river sites contains high sulfide content because the sulfate ion occurs naturally in most water supplies and is present in wastewater as well. Sulfur is required in the synthesis of proteins and is released in their degradation. Sulfate is reduced biologically under anaerobic conditions to sulfide. The sulfur cycle in soft clay was also investigated by Michell (1984). The study investigates on microstructure, strength and compressibility of lime and cement stabilized clays. The microstructure feature of the stabilized soft clays was observed by an Atterberg's limit, scanning electron microscope (SEM) and permeability tests. The tests, carried out to study the strength development and compressibility of stabilized soft clays were the unconfined compression and odometer tests, respectively.

III. MATERIALS AND METHODS

A. Materials Used

For the present study, Expansive black cotton soil, Lime and other additives such as, Sodium Hydroxide (NaOH), Sodium Chloride (NaCl) and Mine tailings have been used. Their physical and chemical properties have been determined.

B. Black Cotton Soil

Black Cotton soils are most characteristic of the Deccan Trap (Basalt) region, spread over the north-west Deccan plateau and they cover the plateaus of Maharashtra, Malwa and southern Madhya Pradesh continue eastwards in the south, along the Godavari and Krishna Valleys. Owing to the high proportion of clay Black Cotton soils are Well-known for their ability to retain moisture. They develop thick fissures in the field during hot weather. This soil is viscous and unmanageable to work, unless they are treated without delay. These soils develop under semi-arid conditions specifically in the areas that are covered with basalt. In the southern region of Tamil Nadu, granites and gneisses with iron content also form black cotton soils under the required semi-arid climatic conditions.

In India 20% of surface deposits are covered with expansive soils. The black cotton soil swells when it comes in contact with water and shrinks on drying. These soils are characterized by inherent swelling and shrinkage characteristics due to presence of Montmorillonite clay mineral, which exhibits volume change behaviour under changes of moisture content. Due to characterizes swelling and shrinkage behaviour of expansive soils leads to the severe damages to the Civil Engineering structures such as cracking in buildings or total distractions of the structure, foundations and pavements.

For the present investigation the Black Cotton soil was obtained from Bhalki, Bidar Dist. Karnataka State, India. It is collected from an open excavation at a depth of 0.6 m below the natural ground surface. The soil was air dried and pulverized after separating the pebbles. This pulverized soil passed through 425 micron IS sieve has been used for this investigation.

The physical properties and chemical composition of oven dried Black Cotton soil was analyzed as per the standard methods and are presented in table 1

Properties	**BC Soil**
Colour	Black
Specific Gravity	2.70
Grain Size Distribution	
Fine Sand Fraction (%)	7.00
Silt Size (%)	17.0
Clay Size (%)	76.0
Atterberg's Limit	
Liquid Limit (%)	74.82
Plastic Limit (%)	47.13
Plasticity Limit (%)	30.84
Shrinkage Limit (%)	8.2
Unified Classification	MH-OH
Compaction Characteristics	
MDD (kN/m^3)	14.3
OMC (%)	29.94

Table 1. Physical Properties of Black Cotton Soil

C. Lime

Chemically pure hydrated lime is obtained from Fisher Scientific chemicals private limited, Mumbai, India has been used in this investigation. The chemical properties of lime are shown in the table 2.

Chemical Composition	$Ca(OH)^2$
Minimum Assay (%)	90.00
Maximum Limits of Impurities	
Chloride (Cl) (%)	0.04
Sulphate (SO^4) (%)	0.4
Arsenic (As) (%)	0.0004
Lead (Pb) (%)	0.004
Insoluble Matter (%)	1.0

Table 2 Chemical Properties of lime

D. Sodium Salts

The sodium salts used in the present study are sodium chloride (NaCl) and sodium hydroxide (NaOH), these chemicals are obtained from Fisher Scientific chemicals private limited, Mumbai, India. The chemical compositions of these reagents are presented in *table 3.*

Chemical Configuration	**NaCl**
Minimum Assay (%)	99.5
Maximum Limits of Impurities	
Sulphate (SO_4) (%)	0.02

Ammonium (NH_4) (%)	0.002
Acidity / Alkalinity (%)	0.1 ml.N/l
Iron (Fe) (%)	0.002
Potassium (K) (%)	0.02

Table 3 Chemical Properties of sodium chloride

IV. EXPERIMENTAL PROGRAMME

The optimum percentages of mine tailings to be added to BCS have been considered. The detailed experimental programme has been planned and is presented in *table 4* and *5* respectively.

Mixture	Test Conducted	Curing in Days
MT alone	Specific Gravity Liquid Limit Shrinkage Limit.	Immediate 0, 7, 14 and 30 0, 7, 14 and 30
MT + 1% to 6% Lime	Liquid Limit	0, 7, 14 and 30
MT + 4% Lime+ 1% NaOH	Specific Gravity Liquid Limit Shrinkage Limit.	Immediate 0, 7, 14 and 30 0, 7, 14 and 30
MT + 4% Lime + 1% NaCl.	Specific Gravity Liquid Limit Shrinkage Limit.	Immediate 0, 7, 14 and 30 0, 7, 14 and 30

Table 4 Experimental Programme for Mine Tailing

Mixture	Test Conducted	Curing in Days
BCS alone	Specific Gravity Atterberg's Limit	Immediate 0, 7, 14 and 30
BCS + 10% to 90% MT	Specific Gravity Atterberg's Limit	Immediate 0, 7, 14 and 30
BCS + 30% MT + 4% Lime	Specific Gravity Atterberg's Limit	Immediate 0, 7, 14 and 30
BCS + 30% MT + 4% Lime + 1% NaOH	Specific Gravity Atterberg's Limit	Immediate 0, 7, 14 and 30
BCS+ 30% MT+ 4% Lime + 1% NaCl	Specific Gravity Atterberg's Limit	Immediate 0, 7, 14 and 30

Table 5 Experimental Programme for Black Cotton Soil Mixtures

V. RESULTS

The specific gravity, Liquid limit, Plastic limit and Shrinkage limit tests were conducted based on the experimental programme. The effects of lime and sodium salts on mine tailings and black cotton soil have been studied on the Index properties. The results and discussions are presented in the following sections.

A. Mine Tailings

The Specific gravity, Atterberg's limit tests were conducted as per the experimental programme. Optimum percentages of lime to be added to the mine tailings has been chosen and treated with 1% sodium salts to study the index properties. The results and discussions are presented in the following sections.

B. Specific Gravity

The Specific gravity of mine tailing alone is 2.77. Further addition of optimum percentage of lime and sodium salts the specific gravity decreases compare to mine tailing alone as shown in *table 6* this is due to the lighter density of lime and sodium salts the specific gravity decreases.

Combinations	Specific Gravity
MT Alone	2.77
MT + 4% Lime	2.75
MT + 4% Lime + 1% NaOH	2.74
MT + 4% Lime + 1% NaCl	2.73

Table 6 Specific Gravity of Mine tailing

C. Liquid Limit

Liquid limit tests have been carried out by adding various percentages of lime to mine tailings. The liquid limit of the mine tailing alone is found to be 31.05%. When mine tailings is treated with different percentages of lime, liquid limit increases from 31.05 to 38.52% for immediate testing. This may be due to the variation in the amount of cementitious compound formed. However, with curing periods the liquid limit increases for 7 days of curing due to flocculation and decreased slightly for 30 days curing due to the reduction in thickness of diffused double layer and also due to the segregation of the particles after a long duration of time. The variation of liquid limit for different percentages of lime for various curing periods is as shown in fig.1.

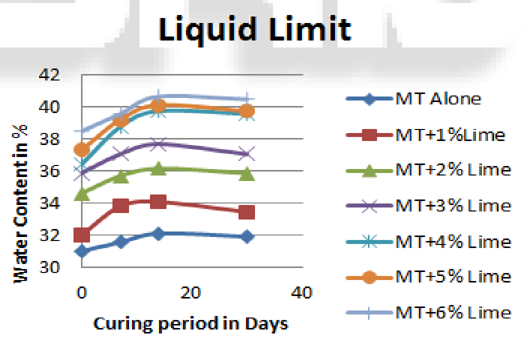

Fig. 1: Liquid Limit of Mine tailings with Varying Percentages of Lime for different Curing periods

The liquid limit of mine tailing treated with optimum percentage of lime is found to be 36.45%. On addition of 1% sodium salts, the liquid limit of mine tailing and optimum percentage of lime marginally decreases for immediate testing. This may be due to the reduction in thickness of diffused double layer by exchange monovalent cations by divalent calcium ions. The liquid limit increases in curing periods due to the formation of C-S-H gel which reacts between the reactive silica and free lime to N-C-S-H by sodium salts, which is more voluminous.

D. Shrinkage Limit

The shrinkage limit of the untreated mine tailing is 23.98%. On addition of 1% lime to the mine tailing the shrinkage limit increased to 27.60% at immediate testing. With further increase in lime content, the value of the shrinkage limit marginally increase and reaches about 31.40% on addition of 6% lime. This may be attributed to flocculation of soil particles reacted with lime.

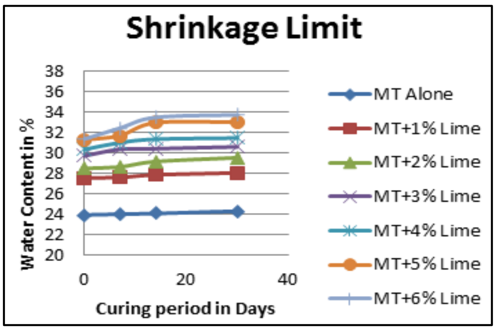

Fig. 2: Shrinkage Limit of mine tailings with Varying Percentage of Lime for various curing periods

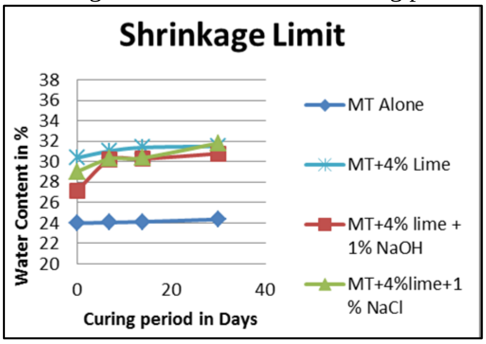

Fig. 3: Shrinkage limit of mine tailing with optimum percentage of lime and sodium salts for various curing periods

As the curing period increases, the liquid limit increases due to the increase in the flocculation and entrapped water in large void spaces of flocculated structure. The liquid limit of black cotton soil decreases with the addition of mine tailing during 30 days of curing periods this may also because of the increase in the dilution effect of the flocculation with curing for longer duration.

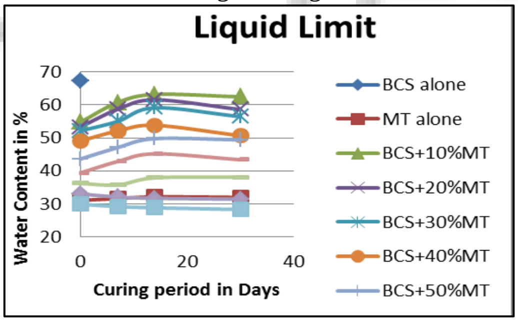

Fig. 4: Liquid Limit of BC soil with Varying Percentages of mine tailings for various Curing Periods

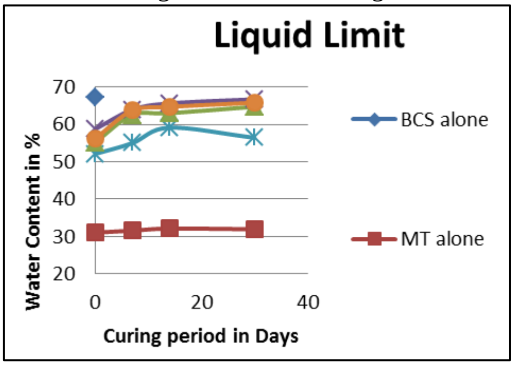

Fig. 5: Liquid Limit of BC soil with optimum percentage of mine tailings lime and sodium salts for various curing periods

As the increase in the curing period the plastic limit of black cotton soil increases with the increase in percentage of mine tailing up to 80% due to the increase in the flocculation and entrapped water in large void spaces of flocculated structure. However, the black cotton soil treated with 90% of mine tailings the plastic limit found to be non-plastic because of the presence of silty particles in mine tailings. The variation of plastic limit for different percentage of mine tailing at different curing period can also be observed from fig.6

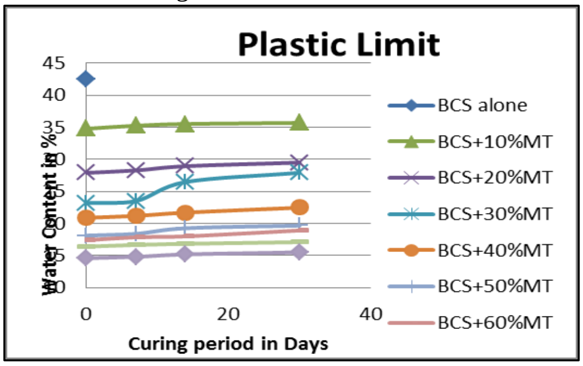

Fig. 6: Plastic Limit of BC soil with Varying Percentage of mine tailings for various curing periods

The plastic limit of Black cotton soil mixed with optimum percentage of mine tailing is found to be 23.23%. On addition of optimum 4% lime to above mixture plastic limit increase marginally about 32.99% and also addition of 1% sodium salts it will also increase the plastic limit about 33.24% in the case of NaOH and for NaCl the plastic limit decrease 28.84% due to lime addition at immediate testing. The increase in plastic limit is due to the enlargement of diffused double layer thickness as shown in fig.7

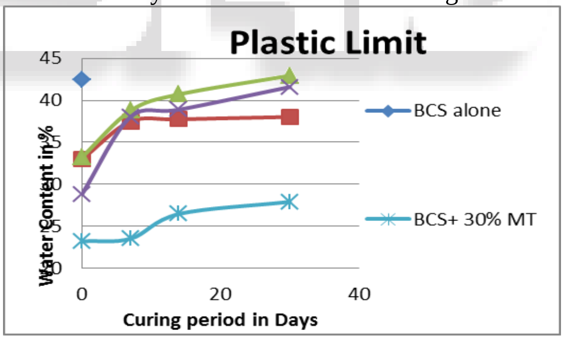

Fig. 7: Plastic limit of BC soil with optimum percentage of mine tailings-lime and sodium salts for various curing periods

E. Shrinkage Limit

The shrinkage limit of black cotton soil one is found to be 7.38%. Increase in the percentage of mine tailing the value of shrinkage limit increases from 7.38% to 19.81% with the addition up to 90% mine tailing on immediate testing. This behavior may be due to the predominance of the coarser fraction of mine tailings. With the increase in the curing periods, the shrinkage limit of various percentages of mine tailings treated with black cotton soil increases. This is due to the effect of flocculation gradually increases with increase in the percentage of mine tailing because of increasing effect of dilution and hence increased the Shrinkage limit. The variation of shrinkage limit for different percentage of mine tailing at different curing period can also be observed as shown in Fig.8.

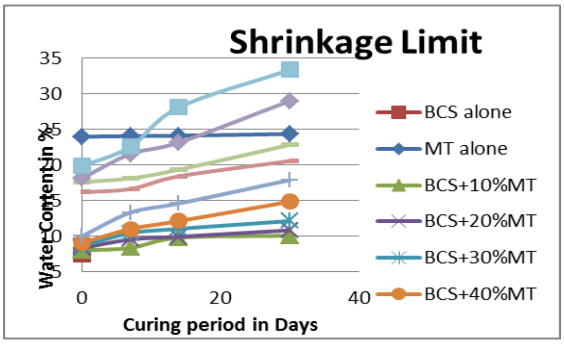

Fig. 8: Shrinkage Limit BC soil with Varying Percentages of mine tailings for Various Curing Periods

The shrinkage of black cotton soil mixed with optimum percentage of mine tailing is found to be 9.58%. On addition of 3% lime to above mixture the shrinkage limit increase marginally and with addition of 1% sodium salts increases the shrinkage limit to about 22.01% and 21.26% and in case of NaOH and NaCl respectively with the immediate testing as shown in Fig.9. The increase in shrinkage limit is mainly due to an expansion of diffuse double layer thickness. With increase in curing periods, the shrinkage limit increases due to the aggregation of the particles after long term curing period and also increase in the dilution effect of the flocculation with curing for longer duration hence the shrinkage limit increased.

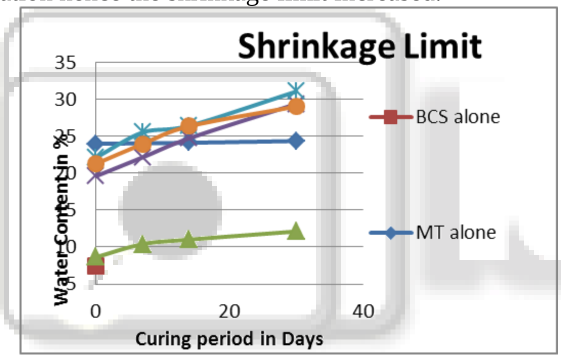

Fig. 9: Shrinkage Limit of BC soil with optimum percentage of mine tailings-lime and sodium salts for various curing periods

VI. CONCLUSIONS

Based on the results obtained experimental programme and detailed analysis of the results the conclusions of the study can be summarized as follows.

- On addition of mine tailings to the black cotton soil the specific gravity increased. This is due to increase in density of mine tailing particles.
- The maximum dry density of the mine tailing decreases with the addition of the various percentage of lime content. Further addition of sodium salts the maximum dry density decreases with increase in optimum moisture content.
- The maximum dry density of black cotton soil increases with the addition of various percentages of mine tailing with decrease in optimum moisture content.
- The addition of various percentage of lime for this combination the maximum dry density increases up to 3% of lime then start decrease with decrease in optimum moisture content. This may be due to flocculation of the clay particles due to an increase in the attractive forces. Further addition of sodium salts the maximum dry density increases with decrease in optimum moisture content.
- The unconfined compressive strength black cotton soil increases up to 30% addition of mine tailing thereafter strength decreases. Hence, 30% of mine tailing with black cotton soil is chosen as optimum percentage. On addition of 1 to 6% of lime to the optimum combination of black cotton soil and mine tailings the strength increases up to 3% of lime content then reduces. Further addition of sodium salts to the above combination the strength increases.
- Irrespective of the clay mineralogical composition of the soils, the void ratio of wet of optimum conditions are always higher than that of dry of optimum and optimum conditions for mine tailing and black cotton soil combinations.
- Reduction in initial and final void ratios occurs with 3% lime treated black cotton soil for all conditions, indicating significant reduction in compressibility me treated black cotton soil, which is desirable in many civil engineering applications.

VII. FUTURE SCOPE OF WORK

The present studies highlight how the mine tailings can be utilized effectively in order to improve the properties of locally available black cotton soil. In the present investigation, the consolidation characteristics have been determined for all the combinations and it was found that the compressibility of black cotton soil treated with optimum percentage of mine tailings – lime and salts decreases. The consolidation tests can be conducted for remoulding water content at different curing periods to study the compressibility behavior for longer duration with the addition of lime and other sodium salts for black cotton soil treated with mine tailings. The utilization of mine tailings for slope stability, for other foundations like residential and industrial buildings, behavior of soils with mine tailings addition to various temperature levels can be studied. The dynamic different types of soils with the addition of mine tailings can be studied and analyzed.

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