Influence of Lime for Enhancing Characteristics of Expansive Soils in Road Works

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Abstract: Expansive soils are found in black cotton soils, which swell or shrink in volume when presented to changes in moisture content. Lime treatment is exhaustively used to increment the properties of sensitive and fragile soils. One of the hugest clarifications behind using lime is to decline the developing presentation of the earth soil. The arrangement of extra safeguards improves the reaction of quicklime (CaO) with water, structures hydrated (slaked) lime (Ca (OH)₂), and thus earth characteristics. The vast inadequacy of employing lime is growing the deficiency of lime offset earth.

Following that, the goal of this study is to see how re-establishing time affects the geotechnical qualities of settled Black cotton soils with lime. These discoveries recommend that adding Lime as a stabilizer works on the strength of black cotton soil. Some of the characteristics of the soil likely to be increased by using stabilizer in this work are UCS (Unconfined Compressive Strength) at different curing periods (7, 14, 28 and 56 days), CBR (California Bearing Ratio) value at unsoaked and soaked and MDD (Maximum Dry Density) decrease at different lime percentages (%) like 2, 4, 6, 8 and 10. The result showed here untreated soil got stabilized by using the stabilizer in certain extent. In this adjustment various rates of cementitious material is added to black cotton soil and directed tests like plasticity, compaction, swell pressure, free swell index (FSI), Coefficient of permeability (k) and CBR (soaked and unsoaked) at various conditions like OMC, OMC+2% water and OMC+5% water, UCS (Unconfined Compressive Strength) was performed. From the test results, it is identified that the stabilization agent decreases plasticity and improves strength characteristics. Addition of stabilizing agent makes the black cotton soil to non-plastic, non-swelling, and attains increase CBR values which are greater than 25% for a dosage of 10% lime at OMC but remaining OMC+2% water & OMC+5% water CBR values are not various much difference as per test results. With the addition of lime, the black cotton soil becomes non-plastic, non-swelling, and has high strengths. Treated soils are used as a development material, for example, a subgrade layer in the development of adaptable asphalt pavements for roads.

Keywords: Black cotton soil, Lime, CBR, Unconfined Compressive Strength (UCS), plasticity characteristics & MDD and OMC.

1. Introduction

Problematic soils are obtainable in massive quantities of Krishna, Guntur & North coastal Districts of AP. Any developments based on such soils have had differential settling, resulting in significant damage. (Black cotton soils 25% - total land area) World over, problem of expansive soils has appeared as cracking and break-up of pavements, railway and highway embankments, roadways,
building foundations, irrigation systems, water lines, sewer lines, canal and reservoir linings. The losses due to extensive damage to highways running over expansive soil sub-grades are estimated to be in billions of dollars all over the world [1].

1.1 Classification of expansive soils
Generally, the soils classified as CL, CI, CH are expansive soils. The soils classified as ML, MI, MH may likewise be extensive. Even the soils classified as SC might be extensive in some cases. Plasticity index, shrinkage limit, linear shrinkage, clay content, potential swell, and other index qualities have been used by various researchers to classify black cotton soils. Table 1 lists the characteristics of black cotton soil [2].

| Description | Range |
|-------------|-------|
| Liquid limit (wₐ) | 40 – 100 % |
| Plasticity index (Iₚ) | 20 – 60 % |
| Shrinkage limit (wₛ) | 8 – 18 % |
| Volumetric shrinkage | 40 – 50% |
| Differential free swell | 20 - 100% |

1.2 Problems with expansive soils

- Diagonal and vertical cracks in interior and exterior walls.
- Horizontal cracks in the interior and exterior walls.
- Longitudinal cracks due to the cantilever action.
- Separation of the roof slab from the interior walls.
- Leaning out of exterior walls.

1.3 Preventive measures for expansive soils
If a soil has a high swell potential, preventive measures are required. These preventive measures can be broadly divided into the following categories:

- Replacement of expansive soil.
- Modification of expansive soil.
- Design of foundation to withstand against swelling

1.4 Replacement of the expansive soil
It is cheap to remove that soil and replace it with a good quality granular soil. The granular soil should be compacted properly.

1.5 Modification of expansive soils
The characteristics of expansive soils (B.C soils) modified to reduce its swelling potential. Some of the common methods are given below:

- Stabilization of soil
- Compaction
• Installation of moisture barriers
• Pre wetting
• Pressure injection

1.6 Stabilization
The practice of blending and combining a stabilizing chemical with a soil to improve the soil's strength and durability is known as stabilisation.

1.7 Uses of stabilization
• Resist shearing within the layer.
• Avoid excessive elastic deflections that would result in fatigue cracking within the layer or in overlying layers.
• Prevent excessive permanent deformation through densification.

1.8 Types stabilization
• 1. Mechanical
• 2. Chemical
• 3. Polymer/Alternatives

1.9 Stabilizing agents
These are main or secondary binders that react with water in the presence of pozzolanic minerals to generate cementitious composite materials when in contact with water. The commonly used binders are:

• Cement
• Lime
• Fly ash
• Blast furnace slag
• Pozzolanas

1.10 Materials used
To learn the performance of Lime on Black cotton soils, various percentages of Lime was added to the dry weight of soil mass also, tried for Geotechnical Qualities like Compaction, Differential Free Swell Index (FSI); Unconfined Compressive Strength (UCS) and Swell Pressure. Black Cotton soil was collected from APCRAD Undavalli Villages, Guntur and RHA was collected from Tadepalli Mandal, Guntur, and Andhra Pradesh, India.[3]

1.11. Black cotton soil
The black cotton soil used in this examination was acquired in Undavalli, Guntur Region, Andhra Pradesh., and its geotechnical characteristics are reported in the tables and figures below.[4]

| Description | Value |
|-------------|-------|
| Table 2. Properties of black cotton soils | |

3
| Property                              | Value  |
|--------------------------------------|--------|
| Gravel (%)                           | 0      |
| Sand (%)                             | 5      |
| Fines (%)                            | 95     |
| a) Silt (%)                          | 49     |
| b) Clay (%)                          | 46     |
| Liquid Limit (%)                     | 72     |
| Plastic Limit (%)                    | 27     |
| Plasticity Index (Ip)                | 45     |
| Type                                 | Brown Clay |
| I.S Classification                   | CH     |
| Specific gravity                     | 2.68   |
| Optimum Moisture Content (OMC) (%)   | 25     |
| Maximum dry density (MDD) (g/cc)     | 1.51   |
| CBR Value (%) (Un soaked condition)  | 1.20   |
| CBR Value (%) (Soaked condition)     | 1.0    |
| Unconfined compression strength (t/m²) in 0 curing period | 10.4 |
| Unconfined compression strength (t/m²) at 7 days curing | 20 |
| Unconfined compression strength (t/m²) at 14 days curing | 21 |
| Unconfined compression strength (t/m²) at 28 days curing | 23 |
| Unconfined compression strength (t/m²) at 56 days curing | 37 |
| Cohesion - C (t/m²)                  | 10     |
| Angle of Internal Friction (Ø)-deg   | 15     |
| Free Swell Index (%)                 | 95     |
| Swell pressure (Ps) (kN/m²)          | 92     |

### 1.12 Particle size distribution curve

The unstabilised BC soil particle size distribution curves of Grain size (mm) vs. Percentage Finer (%) has shown in Figure. 1.
IS sieve analysis was utilized to deliver the molecule size distribution curves, and hydrometer was utilized to get the fine-grained soil molecule size distribution curves. The grading of various particles such as gravel, sand, silt, and clay is shown by the curve (finer).[5]
CBR Graph

Figure 4 Unsterilized soft clay California bearing ration (CBR) load (kgs) Vs penetration (mm)

UCS Graph

Figure 5 Unsterilized soft clay UCS (unconfined compression strength (UCS)) UCS(t/m2) Vs curing period (in days)

1.13 Lime properties

Lime is a cost-effective approach to stabilise soil. Lime modification refers to the increase in strength caused by cation trade limit rather than the pozzolanic reaction's cementing impact (Sherwood, 1993). When quicklime is mixed with wet soils, it ingests up to 30% of its own load in water from the encompassing soil to shape hydrated lime; the heat generated by this reaction causes more water loss by evaporation, resulting in higher soil plastic limit, i.e., drying out and absorption (Euro Soil Stab, 2002; Sherwood, 1993).
The technology of lime stabilisation is generally applied in geotechnical and environmental applications. Encapsulation of pollutants, rendering of backfill (e.g., wet cohesive soil), highway capping, slope stabilisation, and foundation enhancement (e.g., using lime piles or lime-stabilized soil columns) are some of the applications (Ingles and Metcalf, 1972). The presence of sulphur and organic compounds, on the other hand, may obstruct the lime stabilisation process. Sulphate (such as gypsum) reacts with lime and expands, which can affect soil strength.

Lime is a fantastic tool for modifying and stabilising soil beneath roads and other construction projects. The use of lime can significantly improve the sub-grade soil's stability, impermeability, and load-bearing capacity. Lime can be used to change some of the physical qualities of soil and so improve its quality, or it tends to be utilized to balance out the dirt and increment its solidarity and life span. The measure of lime to be added is dictated by the dirt that should be revised or settled. The hydrated lime used in this examination came from a nearby market in Kolkata's Jadavpur area. Table 3 shows the substance attributes obtained from XRF investigation, and Figure 6 shows the XRD examination.

| Constituents | Weight percentage |
|--------------|-------------------|
| SiO2         | 38.271            |
| Fe2O3        | 0.189             |
| CaO          | 57.857            |
| K2O          | 0.065             |
| MgO          | 0.643             |
| TiO2         | 0.026             |
| Na2O         | 0.076             |
| SO2          | 2.873             |

Table 3 Chemical Properties of Hydrated Lime (From XRF analysis) [1]

Calcium oxide (CaO) is the chemical name for lime, which is gotten from the nearby market and contains 95% calcium.

Figure 6 XRD lime pattern [2]
Calcite (Calcium Carbonate), Silica (Quartz), Calcium Hydroxide, and Sulphur dioxide are all found in the XRD pattern of the utilised Lime (SO2). The figure also shows that the lime's silica content is relatively high.

2. Literature Review

Alrubaye AJ et al. studied the soil stabilisation of a soft clay soil stabilised with various percentages of lime and 4% silica fume. The aim of the work to improved the undrained shear strength than other soils. It indicated that the best conditions of lime and silica fume gives the higher shear strength obtained at 5 & 6% respectively. Based on the results the optimum percentage of lime and silica fume at 5 and 6% obtained maximum shear strength and mixing of soil, lime and silica fume increased shear strength and angle of internal friction between soil with lime and soil with silica fume due to the pozzolanic reaction was more effective between the soil particle.[6]

Alrubaye AJ et al. Stabilisation of a soft clay using lime and silica fume as a stabilising agent with various percentages of lime (3%, 5%, 7% and 9%) add soil then observed the soil index properties and engineering properties and using silica fume as a pozzolanic material. The main identification of this mixing the soil lime and silica fume to determine the physical and consolidation properties of the treated soil at optimization of 6% silica fume with different (3%, 5%, 7% and 9%) of lime. Based on the results indicated that plasticity characteristics and compaction properties at 0 to 9% of lime and 6% of silica fume and identified various percentages of lime and silica fume with soil at optimum percentages of lime at 5% and 6% of silica fume gives that treated soil shear strength.[7]

Mohamed SF and Yahya S increasing the bearing loads of soft clay by adding the different additives like fly ash and lime and mainly observed that increase shear strength and decrease the compressibility and conduct various laboratory tests test results at mixing of soil-flyash and lime different percentages to find indexed properties and compaction characteristics both disturbed and undisturbed soil sampling. Two tests carried out are compaction and direct shear strength. From the results, the highest strength of soft clay was at 69 kPa by mixing soil with 12% fly ash + 4% lime.[8]

Lei H et al. studied that Marine clay regularly need enhancements before development and how to balance out such sort of delicate soil has been an incredible test. To address this issue, a recently proposed added substance, which is named anionic polyacrylamide (APAM), with lime was applied to the clay stabilisation. The primary goal of this investigation is to make sense of the impact of APAM on lime-treated marine clay and the micro mechanism of stabilisation. The unconfined compressive quality (UCS) tests and oedometer tests were performed to explore the mechanical properties of stabilised clay; The test results show that with APAM measurements expanding, the adjustment impact originally upgraded and, in this way, debilitated[9].

Khazaei J & Moayedi H has indicated Black cotton soils are being a expansive in nature of danger to the people since it finally causes financially loss, phenomenal damage to structures and system. For all of the introduced included stabilisers, treated samples containing 4, 6, 8, 10 and 12% obsession were prepared. The results of compaction, extending estimation, Atterberg limits, and unconfined weight quality (UCS) tests showed a reduction in developing potential. This miracle was added to the checked addition in UCS and shear nature of improved models by waste and lime.[10]

Gharib M et al. stated our construction structure faced so many problems to construction Use of soft clay soils. Use some ground improvement techniques as a stabiliser, and reinforcement methods is use as a sub grade and embankments in road works. This project, the impact of chitin nanofiber and rice husk ash as added substances on the conduct properties and bearing resistance of soft soils by considering the preparing time period of 7, 28, 42 and 90 days was researched. To find the properties
of treated soil FTIR, XRD and SEM are evaluated. Various rates of added stabilising agent (1, 2, 4, 6 and 8%) with varieties in chitin nanofiber and rice husk debris proportion were added to soil containing 6% lime at 2% of additives and 6% of lime.[11]

Kamaruddin FA et al. Studied that. Not only is the material environmentally friendly, but it is also inexpensive. In this study, two types of soil stabilizers—lime and alkaline activator (AA)—were investigated in coastal clay soil with the addition of treated coir fibre as soil reinforcement. The addition of fibre in the treated marine clay soil has had a much effect in increasing the strength of the soil. There, conduct the treated soil indirect tension test, flexural test and unconfined compressive strength test (UCC) were performed at three different curing times (7, 28 and 90 days) on both conditions. The results are the addition of fibre in both lime and alkaline activation indicates an increase the soil behaviour more ductile from brittle and after shearing, microstructural investigations using a Field Emission Scanning Electron Microscope (FESEM) and an Energy Dispersive X-ray (EDX) were performed to assess the changes in the soil before and after treatment.[12]

Tulasi Sai Krishna et al. Our proposed APCRDA area most of the top surface area is occupied by black cotton soil. The current experimentation is with Bagasse Ash (BA) and Brick Dust (BD). Do the experimentation with and without including added substances, contrast and those two arbitrarily including rates 15%, 20%, 25%, 30%, 35% Brick Dust. Bagasse Ash is use constantly 10%. From that: Black cotton soil, Bagasse Ash, Brick Dust, physical properties, Shear Strength tests, Swell Pressure test, and compressive test.[13]

Krishna.M et al. Removal of waste materials including waste plastic bags has become a major issue and waste plastics are burn for evident removal which cause natural contamination. This plastic waste covered aggregate is blended in with hot bitumen and the result about blend is utilized for road development. In my research work I have done an intensive report on the system of utilizing plastic waste in bituminous blends and introduced the different tests performed on aggregates and bitumen.[14]

J. Chetan Anand et al. the populace is expanding step by step so that no-of development exercises are expanding day by day which transforming the world into a substantial wilderness. the requirement for land is expanding for development reason. Black cotton soil is having a place with one of the significant soil stores in India. the idea of the dark soil is highly. This test study was done one dark cotton soil to work on its attributes by adding admixtures like quarry residue and lime. different properties like fluid breaking point, plastic cut-off, most extreme dry thickness, ideal dampness content and California bearing proportion. trial study shows. (10)

Srinivasa Reddy K et al. Now days the construction on expansive soil is a difficult task for the engine as structure resisting in expansive soil cracks without any problems. Stabilization can be done in a number of ways. method since the stabilizer used here is waste from sugar cane material, which is available cheaply. Bagasse Ash is a fibrous waste product of sugar cane industry. It is already causing environmental pollution which calls for the usage of waste. The Different dosage of bagasse the taken soil sample, the performance of bagasse ash was evaluated using physical and strength performance tests namely, compaction, unconfined, unconfined compressive strength. These tests were conducted to evaluate the improvement in strength characteristics of the sub grade soil.[15]

Megnath Neopaney et al. Soil stabilization can be done in number of ways. But the stabilization using waste plastic strips is an economic method since the stabilizer used here is waste plastic materials, which are easily and cheaply available. Plastic, such as shopping bags, is used as a
reinforcement in this paper to perform CBR studies while mixing with soil to improve subgrade soil engineering performance. Plastic strips made from scrap plastic were thrown into the soil at random. The inclusion of waste plastic strips in soil in appropriate amounts improved the strength and deformation behaviour of subgrade soils significantly, according to CBR tests. The proposed technique can be beneficial in embankment/road construction, industrial yards, and other applications.[16]

Y. Keerthi et al. Day by day increasing demand of cement results in intense collection of kiln dust from cement plants. The disposal of this fine dust becomes an environmental threat. In order to overcome this problem, in various parts of the world, research is being conducted to determine the most cost-effective and efficient methods of using cement kiln dust (CKD) in various applications such as soil stabilisation, cement production, pavements, waste product stabilisation, agriculture, and cement products, among others. The stabilisation of clayey soil with cement kiln waste is the subject of this paper. The soil from Ravendrapadu, Andhra Pradesh, is mixed with CKD in various proportions to determine parameters such as dry density and moisture content. Ideal values are obtained at a 50 percent proportional mix of CKD in total percentage by examining the values obtained [17].

T.V Sai Krishna et al. Soil stabilisation can be accomplished in a variety of methods. The purpose of soil stabilisation is to increase the strength of the soil and the carrying capacity of subgrade soil. On the stabilisation of soil in flexible pavements, geo grid is the most commonly utilised stabiliser. Geo grids are primarily utilised for soil reinforcement in a variety of building projects. The main topic of discussion in this paper is the use of geo grids to stabilise black cotton soil in flexible pavements. The use of geo grid to raise the CBR value of black cotton soil determines the strength of black cotton soil in flexible pavements.[18]

D.V.K.Sravan et al. To enhance the soil, we conducted some studies on black cotton soil. Because black cotton soil is a very expansive soil, it is not suitable for any construction work under basements. As a result, our experiment demonstrates how to employ black cotton soil for construction applications. As a result, we've conducted studies on how to make black cotton soil more beneficial by adding lime and pond ash. Changes in the qualities of soil types, such as the liquid limit, plastic limit, and maximum. As a result, we used 10 percent, 15 percent, and 20 percent pond and lime in various amounts. As a result, we make use of waste from the thermal power plan.

D. Srinadh et al. Soil stabilisation is a new technique for soil modification that is used in building in our daily lives. Land is becoming scarce as a result of population growth; thus, we must develop in the existing space. Soil stabilisation or soil modification is the term for the approach we apply. As a result of the availability of admixtures in the economy, we can simply improve the strength of the soil by adding these admixtures utilising industrial waste that is available at a low cost. Following the addition of the admixtures, the soil should be evaluated using the simple U.C.C (Unconfined Compressive Strength) and California Bearing Test (CBR) tests, as well as some other basic tests in order to test the enhanced strength of the soil, tests such as MDD (Maximum Dry Density) & OMC (Optimum Moisture Content), Plasticity index, and liquid limit should be carried out. [19]

Satya Ravi Teja et al. Contamination of soil occurs due to presence of heavy toxic metal and combination of oil, petroleum, Greece where the automobile repair works done, so that the soil is weak in strength. There are many additives are there to strengthen the soil like lime, cement, fly ash, GGBS etc. Because of having more binding capacity cement is selected as a stabilizing agent moreover the area which is selected in CRDA region in A.P (17).
M. Sai Nandan et al. The purpose of this research is to investigate the possibility of stabilising soil with rice husk ash and coconut coir fibre, therefore repurposing waste resources and offering a cost-effective and environmentally friendly soil stabilisation approach. Various stabilisation strategies can be used to improve the stability of a soil that lacks it. Rice husk ash with coconut coir fibre in various percentages (5 percent to 25 percent). With the sample, the procedures were carried out in five proportions: 5%, 10%, 15%, 20%, and 25%. Table 3 shows the optimum value of the assessment at a 15% proportion, i.e., the value of unconfined compressive strength is 142kN/m2. Expansive clays are difficult to work with and are not suited for construction without certain precautions. [20]

3. Experimental Conditions

3.1 Laboratory Testing

The soil was subjected to the following tests. The soil's index and engineering properties were calculated.

- Grain size analysis (IS:2720-part 4,1985)
- Atterberg limits (IS:2720-part 5,1985)
- Specific gravity(IS:2720-part 3,1980)
- Proctor’s compaction test (IS:2720-part 8, 1983)
- Unconfined compressive strength test (IS:2720-Part 16, 1987)
- Consolidation Test (IS:2720-part 15,1965)
- California bearing ratio test (IS:2720-part 16, 1987)

4. Results and Discussion

4.1 Effect of Lime on Properties of Expansive Soils

Table 1 property (plasticity characteristics, density, UCS, and CBR (percent) of soil lime mixes were added and successfully mixed at various percentages of lime, i.e., 0,2,4,6,8,10 percent by dry weight of BC soil, to revise the influence of lime on Black cotton soil [4].

![Figure 7 Lime % Vs water contents](image)

Percentage of lime is increase liquid limit and plasticity index values are decrease and plastic limit values are increasing. After it became non-plastic, this behaviour persisted up to 6% of lime.
Table 4. properties of BC soil with lime mixes

| Lime | WL | WP | IP | OMC (%) | MDD (g/cc) | UCS(MPa) in days | CBR (%) |
|------|----|----|----|---------|------------|-----------------|---------|
|      |    |    |    |         |            | 7               | 14      | 28       | 56       | Un soaked | Soaked |
| 0    | 72 | 27 | 45 | 25      | 1.51       | 0.2             | 0.21    | 0.23     | 0.37     | 1.2        | 1      |
| 2    | 65 | 30 | 35 | 27      | 1.5        | 0.35            | 0.41    | 0.52     | 0.65     | 5          | 6.2    |
| 4    | 51 | 31 | 20 | 28.3    | 1.48       | 0.45            | 0.53    | 0.7      | 0.84     | 10         | 11.8   |
| 6    | 35 | 35 | 0  | 29.5    | 1.45       | 0.68            | 0.73    | 0.95     | 1.05     | 16         | 18.5   |
| 8    | NP | NP | NP | 30.5    | 1.43       | 0.85            | 0.94    | 1.12     | 1.42     | 22         | 23.5   |
| 10   | NP | NP | NP | 31.6    | 1.41       | 1.04            | 1.1     | 1.28     | 1.55     | 26         | 27.1   |

The decrease in liquid limit is reduced due to calcium ion absorption on the surface of clay particles, and the plastic limit is increased due to the development of shear resistance at the inter particle level, which necessitates more water to assemble for rolling [21].

Figure 8 Lime % Vs OMC

Increasing the lime proportion, The OMC value is gradually increasing, while the MDD value is decreasing. This increase in OMC values is attributed to the development of a flocculated structure that resists compaction and a decrease in dry density due to less solids occupied in a given volume due to clay particle structural arrangement [22].

The type and quantity of probable reaction products were found to be roughly linked to the increase in soil strength (i.e., the OPC hydration reaction product, CSH for short-term strength and pozzolanic reaction product for long-term strength increase).
First, because of the high ionic strength of the pore water, the plasticity values of the BC soil are reduced by the exchange of calcium ions in the pore water with monovalent cations on clay surfaces and by compression of the adsorbed layer.

Second, the C-S-H gels formed by hydration process and pozzolanic reactions between the bind of solid particles together. This binding produces a stronger soil matrix, resulting in an increase in compressive strength. A strength characteristic of soil and lime mixes Optimum Moisture Content (OMC). Increasing percentage of lime increases UCS values (7 and 14, 28 and 56 days) with curing time. The increases in compression strength values are due to development of cementitious compounds [23].
Table 5. properties Free Swell Index (FSI), swell pressure and permeability (k) of soil with lime

| Lime (%) | FSI (%) | Swell pressure (kN/m²) | Permeability (K) cm/sec |
|----------|---------|------------------------|------------------------|
| 0        | 95      | 92                     | 4.61X10⁻⁷              |
| 2        | 84      | 67                     | 5.3X10⁻⁷              |
| 4        | 59      | 30                     | 7.10X10⁻⁷             |
| 6        | 19      | 5                      | 8.4X10⁻⁷              |
| 8        | 0       | 0                      | 9.7X10⁻⁷              |
| 10       | 0       | 0                      | 1.2X10⁻⁶              |

Percentage of lime is increasing the CBR values are increasing. Development of cementations compounds between clay and lime particle which increases shearing resistance at internal particle level[7].

Figure 11 Lime Vs CBR

Figure 12 Lime (%) Vs Free Swell Index (%)
Increasing percentage of lime and percentage of free swell values are decrease. At a quantity of 8% lime it became non-swelling. The reduce in swelling characteristics is due to the decreasing repulsive forces between fine particles.

| Lime  | Un soaked | Soaked |
|-------|-----------|--------|
| 0     | 1.0       | 0.95   |
| 2     | 5.7       | 6.1    |
| 4     | 9.1       | 11.1   |
| 6     | 15        | 17.5   |
| 8     | 20        | 21.5   |
| 10    | 25        | 26.15  |

Percentage of Lime is increasing Swell pressure values are decreasing. At 6% of Lime the swelling pressure became 5 Kpa which soil-Lime mix Shows very low swelling level. At 8% of lime, it shows non-swelling. This is due to decrease of repulsive forces and increase shearing resistance at particle level reduces and This thrust transfer to the surrounding of environment in the form of reduction of swelling pressure values. Increasing percentages lime and increases the coefficient of permeability values. The development of the floculated structure of the particles is responsible for the increasing coefficients of permeability values.
5. Conclusion

- Black cotton soil is Fine grained soil and plastic soil.
- It is an untreated more swelling and plastic soil with a maximum dry density (MDD) of 1.51g/cc and an optimum moisture content (OMC) of 25%, CBR values of 1.0, 0.95 & 0.90
percent (soaked) at different water contents like OMC, OMC+2 percent & OMC+5 percent, and UCS of 10.4, 20,21,23 & 37 t/m² at different age curing (7,14,28 & 56 days).

- The addition of 6% lime transforms the Black cotton soil (Expansive soil) from a high-swelling to a non-swelling state, increasing the unconfined compressive strength values by 100-0 percent. 0.2 Mpa to 1.28 Mpa.
- Improves its Plasticity characteristics up to 6% it became non-Plastic.
- Improves its compaction characteristics such as OMC from 25% to 31.6% and decreases MDD from 1.51 g/cc to 1.41 g/cc and remaining soil characteristics.
- Lime 6% improves the CBR values at various water contents (like OMC, OMC + 2% water & OMC+ 5% water) such as 20%-30%. It can be used as Embankment of road works.

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