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Lime Pile Technique for the Improvement of Properties of Clay Soil

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Abstract: ***Soil improvement is one of the basic requirements for the preparing in situ soils for the appropriate strengthening, stiffness, and stability in civil engineering designs and applications. The modification technique, which involves mechanical, thermal and chemical components, requires monitoring techniques to determine its efficiency and suitability. This study examines the geotechnical improvement of properties of clay soils using the lime pile technique on a laboratory scale model. The clay-lime physicochemical reactions resulting from cat ion exchange were examined through basic experimental analyses. Remolded compacted clay soil blocks were carefully prepared in rectangular test tank with lime piles installed in them. The treated soil block properties were then investigated as a function of lime pile at different curing periods. The curing periods are 28, 60, 90 and 120days etc…It was observed that there are significant changes in the atterberg limits, shrinkage, compaction characteristics, and strength of the treated soils due to the clay-lime reactions. The results indicate that these reactions have remarkable effects on the lime pile treated soil and produced strong interpartical bonds and unconfined compressive strength of the soil. This is attributed to the migration of Ca^{2+} and $Mg2^{+}$ ions from the lime piles into the soil, flocculation of particles, and pozzolanic reactions. The significant shear strength values suggest that their correlative changes can be used as monitoring technique to determine the improvement in geotechnical properties of chemically treated soil.***

Keywords: soil, lime piles, physicochemical reactions, Atterberg limits, Omc and Mdd, shear strength

1. Introduction

Lime column technique has been applied successfully in recent years to improve the physical and mechanical properties of the soils. Both the dry and wet lime mixing are carried out by injecting a preferable pressure into soil and form a lime-column in-situ. This technique increases soil bearing capacity and reduces soil settlement owing to improving of soil strength and stiffness. A study carried by on full-scale model showed that the stiffness of the improved soil using lime column increased more significantly than that of lime-cement column. Researchers such as Shen et al(2003),Tonoz et al (2003),and Budi et al (2003)studied separately the strength of the soil surrounding the lime column. They reported that the soil strength increased near the column to a distance up to 2 to 3 times of the column diameter in radial direction. But, the effect of strength change beneath the bottom of lime column was not studied. It is reasonable to assume that the lime will flow easily downward into soil in vertical direction and the soil strength may also increases with the availability of lime. After lime column installed, the lime or calcium ions migrate into soil surround the lime column. The soil properties around lime column will change due to consolidation, densification and hardening resulted by the chemical reaction between lime and soil. For an efficient stabilization, calcium and hydroxyl ions should migrate through the clay, because hydroxyl ions cause highly alkanic conditions give rise to the slow solution of alumino-silicates which are then precipitated as hydrated cementitious reaction products. These reaction products contribute to flocculation by bonding adjacent soil particles together and curing is allowed the clay soil is strengthened. This mechanism will control the strength of the soil surround the lime column. The soil the center of the lime column both in radial and vertical direction.

2. Review of Literature

Kennedy et.al (1987) observed an increase in the unconfined compressive strength with the addition of lime to some clay soils.

Allen, et.al., (1977) reported that higher than normal temperature activate the strength producing pozzolanic reactions of lime –soil mixtures.

Lashed and Mizrahi (2008) concluded that hydrated lime treatments are very effective in reducing the swelling pressure and consequently the swelling potential of the treated expansive clay soils.

Tonoz et al. 2003; Arnsberg 2006; A typical expansive soil is characterized with high plasticity, excessive heave, high swell,and shrinkage potential that may result in damages to civil engineering structures.

Mitchell and Hooper (1961) conventionally, geotechnical properties of lime pile–treated soils are dependent on their ionic content, type of lime used, curing time, curing temperature and water content.

Timo 1998; Friedman 2005 The movement of ions in clay soils is attributed to the degree of saturation, magnitude of electric field, temperature difference, amount of fines, organic content, pore ionic concentration, and particle structures.

Allele. Al., (1977); Saber and Parches, (1979); Kennedy et. Al.,(1987) Extensive research has been conducted on the effects of lime stabilization on the engineering properties of natural clayey soils.

3. Materials

In this study, the laboratory tests were performed on an expansive clay soil extracted from Thadigotla cheruvu, near Kadapa. The physical and index properties of the soil are given in table 1.The soil used in this study has a high plasticity index,Ip 45

According to the Unified Soil Classification system (USCS), it is classified as a CH soil, namely with very high plasticity. In the study, high-calcium quicklime was utilized in lime piles as the chemical addition and stability agent to modify the expansive soil. The physical and chemical properties of quicklime are provided in table 2.

Table 1: Physical and index Properties of the natural clay soil

Soil Property	*Value*
Free swell Index	63.33%
Specific Gravity	2.68
Clay size Fraction	64%
Silt size Fraction	26%
Sand size Fraction	10%
Uscs classification	CH
Max Dry Density(g/cc)	1.49
OptimumMoistureContent (OMC)in %	26%
Liquid Limit, LL (%)	78%
Plastic Limit,PL(%)	33%
Plasticity Index, I(%)	45%
Linear Shrinkage,(%)	20%
UCC value(kg/cm^2)	1.5

Table 2: Chemical and physical properties of the quicklime

Property	*Value*
Cao (%)	87.20%
Mgo (%)	2.13%
Other Compounds (%)	9.42%
Loss in Ignition (%)	1.25%
Practical size(µm)	<90
Partical Density (g/cc)	1.15

4. Methodology

Sample Preparation

The natural clay soil was oven-dried at 50° C, then mechanically ground into a pulverized form. The pulverized dry soil sample was mixed with water in an appropriate quantity using the initially determined in situ moisture content. The prepared wet soil was packed in an airtight polythene bag where it remained for 24h,which allowed intimate curing of the soil-water admixture and prevented water loss. The desired amount of wet soil needed to be compacted in the test tank was predetermined from the in situ bulk density and water content values to simulate the natural field conditions. The soil was compacted in a rectangular test tank that was 40cm in both diameter and height. The test tank was partitioned into four equal layers of 9cm each by height.

The compaction of the wet soil was performed in four successive layers. The moist soil mass of known weight was placed in the test tank for each layer and compacted using a modified rammer until the required volume and bulk density were achieved. This was performed in conformity with American Society for Testing and Materials (ASTM 2002) standard 1557.This was subsequently done for the other three layers to achieve the same bulk density up to the 36cm mark in the test tank. In the test tank, 4cm in height was left above the soil block for the moveable steel plate cover to fit into the tank for proper moisture control. The physical properties of the compacted soil block in the test tank are given in table 3.

Table 3: Physical properties of the soil block in the test tank

PROPERTY	VALUE
In situ Water content W (%)	30
Insitu bulk density ,(g/cc)	1.88
Dimension of compacted soil block in test tank(cm)	B=30,H=40
Volume of soil sample in test tank (cc)	45238.93
Mass of the compacted soil in test tank(g)	85049.20

Lime Pile Installation

It has been shown that prior to the rainy season is the most suitable period for the in situ installation of lime piles and other deep chemical stabilization techniques in arid and semi aired regions of the world. The lime pile technique uses the pore fluid to aide physicochemical transfer of cat ions from the piles into the surrounding soil. In field applications, a hollow tube is forced into the ground to the desired depth and the binding agent is applied with air pressure into the soil holes, cracks, fissures, and crevices as the tube is being extracted. The technique was simulated in the laboratory with the installation of five columns in the compacted soil block. Each of these columns were 3cm in diameter and 30cm height and were installed in the soil blocks using a hollow Poly Vinyl chloride(PVC) pipe that had openings at both ends.

Figure 1: Lime pile installation during at laboratory

The PVC pipe had an internal diameter of 3cm with a about 45cm.The PVC pipe length was chosen to aide easy to penetration into the soil block and created the columns without interfering with the properties of the compacted soil block. The advantage of using a PVC pipe was to create smooth holes in the soil block without having to clean the holes a spiral brush prior to filling with lime. Then each column was filled with powdered quicklime of uniform mass. The quicklime was applied in three successive uniform layers and layer was lightly compacted to form the lime piles. Figure presents the cross-sectional and plan views for distribution of the five lime piles installed within the compacted soil block in the test tank.

Experimental Setup

After the lime pile installation, the setup was covered with a thin perforated fiber cloth and then sandy soil of particle size 2mm was poured on top of the cloth up to the 37cm position (by height) in the test tank as shown in fig. This was to provide a slow absorption rate of water by the lime piles and to

1) A void a sudden hydration reaction,
2) Minimize the lateral expansion of the lime piles, and
3) Prevent formation of cracks in the soil block.

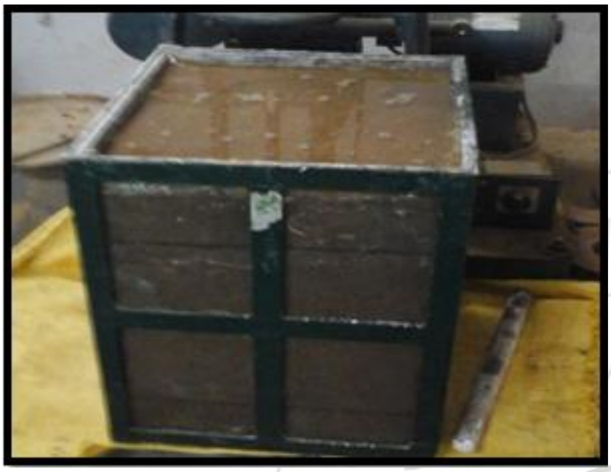

Figure 2: Experimental setup at laboratory

The fastened moveable steel plate of 0.5cm thickness was positioned in the setup to fit into the tank to maintain the moisture content in the soil block. In the field application o Lime piles or lime columns are often constructed before the rainy season. During the wet season, the in situ soil and dry lime pile are supplied with moisture, which allow migration of cat ions from the lime into the soil solution. In the laboratory, dry lime and soil block piles absorbed the water, and then the Ca^{2+} and Mg^{2+} ions were allowed to diffuse into the solution from each pile. The complete laboratory setup was then filled with water up to a point of the 40cm mark. In this study, the water supply was kept constant in the setup to keep the moisture content of the soil block at least 30%.This was to prevent the soil block from drying or cracking. The soil block was left to react chemically with the quicklime piles for different curing periods: 28, 60, 90 and 120days.

Sample Extraction

The sample extraction was conducted at different curing periods within different radial distances to the lime piles in the treated soil block. The extraction was conducted using molds suitable for specific experimental test methods. Steel molds befitting the desired sample dimensions were pushed slowly into the treated soil block. This was followed by sample extrusion from the molds and the samples were trimmed to the chosen standard ASTM dimension for unconfined compression. The undistributed specimens were carefully prepared from the undistributed large soil block. During the extraction and extrusion processes, the soil specimens were handled carefully to prevent disturbance, loss of water content and cracking in the samples. After the extraction, the specimens in the mold were trimmed on both sides to the longitudinal axis of the specimen. Compression or any other related disturbances were also avoided when using the extrusion devices by applying the minimal effort at a very slow rate. Immediately after their extraction, the soil samples were kept in airtight polythene bags before conducting the appropriate tests. The samples used to determine changes in the physical properties after the treatment with lime piles were extracted from the treated soil within different curing periods to the lime piles in the rectangular test tank are illustrated.

Figure 3: Sample extraction during at laboratory

5. Results and Discussions

The physical and engineering properties of the soil block treated with lime piles were determined using. Atterberg limits, Standard Proctor compaction, unconfined compressive strength

Effect of Lime Pile treated on Liquid limit of Black cotton Soil

The liquid limit of black cotton soil is found to be 78%.The lime pile treated with black cotton soil, liquid limit decreases for immediate testing due to reduction in the specific surface area of the soil, the consequent decrease in the diffuse double layer thickness possibly accounts for the lower liquid limit of the treated soil during initial stages. The introduction of lime piles into the compacted soil block produced calcium and hydroxyl ions in the soil mass. In the presence of water, the Ca^{2+} ions diffused into the soil block and caused spontaneous physicochemical reactions that altered the soil mineralogical and textural characteristics. The soil fines reduced with significant reduction in the Liquid Limit, LL, 73%, 67%, 62%, and 57% within curing periods of 28, 60, 90 and 120days, respectively.

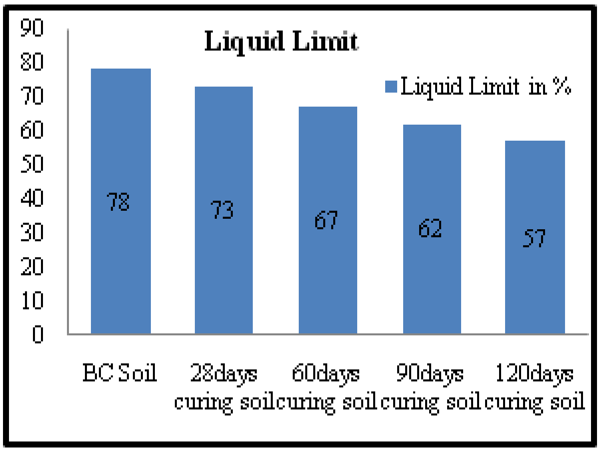

Figure 4: Variation of Liquid Limit with Different curing periods of Lime pile treated with Black cotton Soil

Effect of Lime pile on Plastic limit of Black cotton

The plastic Limit of Black cotton Soil was found to be 33%.The plastic limit decreases immediately after the increases of curing days of lime pile treated with Black cotton Soil. The Plastic limit reduced as the lime diffused into the soil. The Plastic limit results indicate that the chemical effects of Ca^{2+} ion migration in the treated soil block caused dehydration, agglomeration, and flocculation of the clay particles. The soil modification, which provided the high calcium concentration (Ca^{2+} ions), can be attributed to the elimination of attractive forces within the clay particles and contributed to the collapse of the Diffused Double Layer (DDL).Conclusively, it was observed within the "concentration Zone" of Ca^{2+} ions, the Plasticity of the treated soil decreased due to flocculation and agglomeration of the soil particles. The soil fines reduced with significant reduction in the Plastic Limit,PL,29.2%,26.8%,22.6% and 20.5% within curing periods of 28,60,90and 120days respectively. The Plasticity Index reduced 45%, 42.8%, 40.6%, 40.2% and 37.5% within curing periods 28, 60, 90, and 120days.

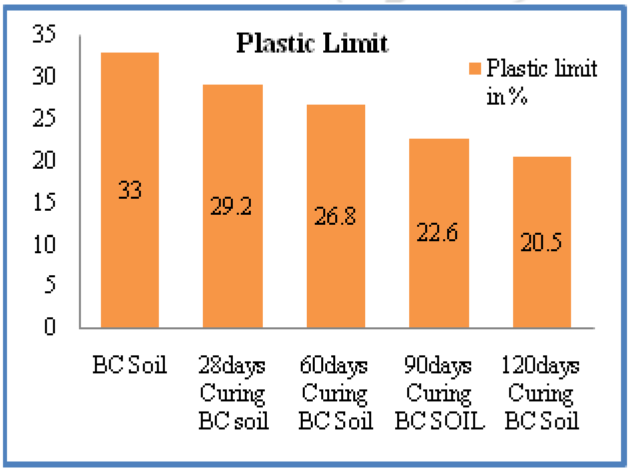

Figure 5: Variation of Plastic Limit with different curing days of Lime pile treated with BC Soil

Effect of Lime pile treated on Shrinkage Limit of Black cotton soil

The Shrinkage limit of black cotton soil is 16.36%.The different curing periods of lime pile treated with black cotton soil the shrinkage limit increases marginally on immediate testing as shown in table 4.3.The increase in shrinkage limit may be due to decrease of diffuse double layer thickness by cat ion exchange. The shrinkage limit increases due to the flocculation of clay particles. The soil fines increased with significant increase in the Shrinkage Limit, SL, 17.28%, 19.32%, 20.42% and 22.12% within curing periods of 28, 60, 90 and 120 days respectively.

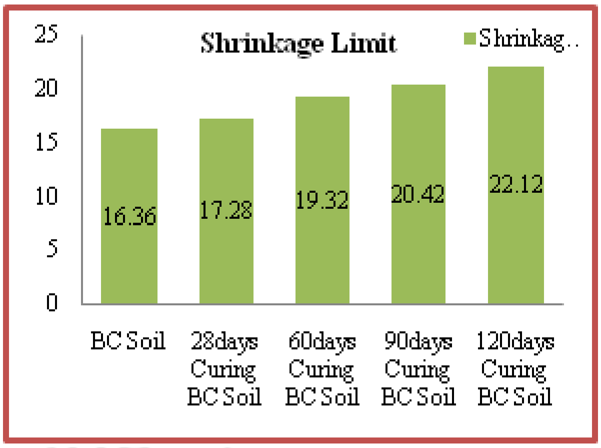

Figure 6: Variation of Shrinkage Limit with Different curing periods of Lime pile treated with Black cotton Soil

Effect of Lime pile treated on compaction of block cotton soil

The disturbed soil samples extracted from the lime-pile treated soil blocks were subjected to the standard proctor compaction test. The fig shows the compaction characteristic of the treated soil samples tested at different curing periods and the properties changed in response to lime treatment after different curing periods. It was observed that there were changes in the fabric of the treated soil along different curing periods. The bond strength within the adjacent flocculated soil particles when curing occurs strengthened the treated soil block. The results of the standard proctor compaction test show that the maximum dry density of the treated soil linearly increased with up to 120days.The optimum water content of the treated soil linearly decreased with up to 120days.This can also attributed to an increment in bond strength resulting from physicochemical and mineralogical changes in the soil at each curing period.

The decrease in OMC of expansive clays treated with lime may be caused by flocculation so that when compacted the soil each have an increased volume of voids compared with untreated soil, in addition the increase in hydroxyl ions liberated by lime, increases the affinity of the surfaces of clay particles for water (Bell, 1987). The decrease in optimum moisture content is due to the increasing demand for water by various cat ions and the clay mineral particles to undergo hydration reaction. The decrease in optimum moisture content is probably a consequence of the additional water held within the flocculent soil structure resulting from lime interaction and exceeding water absorption by lime as a result of its lower specific gravity.

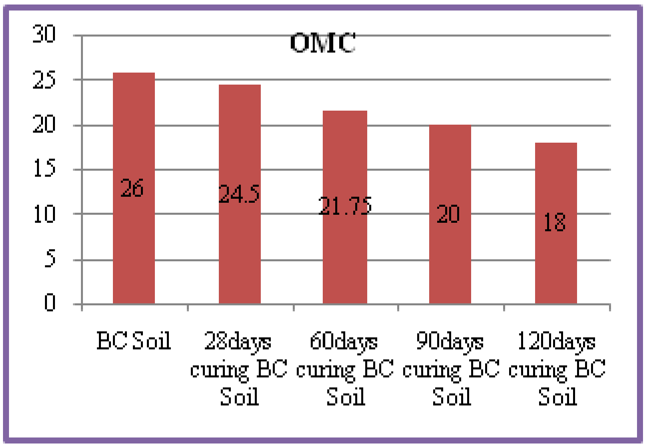

Figure 7: Variation of Optimum Moisture Content (OMC) with Different curing periods of Lime pile treated with Black cotton Soil

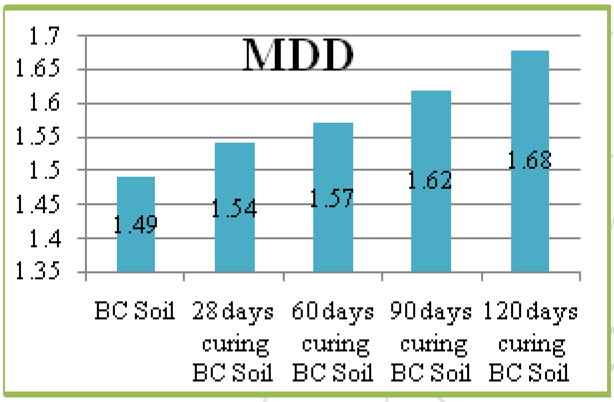

Figure 8: Variation of Maximum Dry Density (MDD) with Different curing periods of Lime pile treated with Black cotton Soil

Effect of Lime pile treated on UCC Values of Black cotton Soil

The results of the unconfined compression tests in accordance with on different soil blocks treated with lime piles. The specimens were extracted within the treated soil blocks at different curing periods. This was to investigate the variation in the changes of strength of treated and untreated specimens. The fig provides a “strengthening” of stress-strain behavior of the soil blocks treated with lime piles. This is attributed to the diffusion of lime into the soil block, which brought about the dissolution of alumina and silica compounds in the highly alkaline environment during the clay-lime physicochemical reactions. This brought about the exchangeable monovalent ions of sodium and potassium with divalent calcium ions to form cementitious compounds of calcium aluminates and silicate hydrates (CAH and CSH, respectively).Evidently, the increase in curing periods resulted in the formation of more granular and less plastic soils due to the increase in the formation of these new cementitious compounds CAH and CSH. Cementation caused a reduction in DDL thickness and subsequent flocculation of the soil particles. The soil exhibited reduction in plasticity with improved shearing resistance. Fig indicates the increase in shear strength of the lime pile-treated soils. The unconfined compressive strength (q_u) of the treated soil was increased by in curing periods of 28, 60, 90, and 120days, respectively. The results show that the increments in strength (q_u) of the treated soil specimens are dependent on curing period. The significant peak the indicates the strength increment that was observed in the treated specimens extracted to the lime piles with longer curing periods. Test results show that the treated specimens formed a granular-like material. Diffusion of lime from the piles modified the textural, mineralogical, and physicochemical properties of the soil blocks and produced a significant increase in strength, stiffness, and durability.

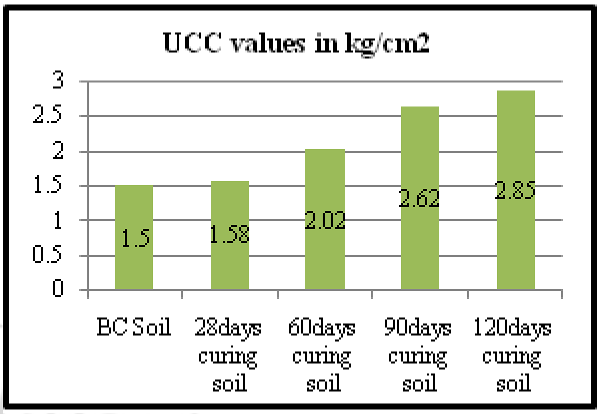

Figure 9: Variation of Unconfined Compression values with Different curing periods of Lime pile treated with Black cotton Soil

6. Conclusions

Test results indicate that the engineering properties-such as Atterberg limits, strength of the treated clay soil changed at different curing periods of the treated soil block. Based on the results obtained from experimental program and thorough analysis of the results the conclusions of the study can be summarized as follows,

1) Reduction in liquid limit and plastic limit values with increase in curing periods of lime piles. The liquid limit values are 78% for BC soil, 73% for 28 days, 67% for 60days, 63% for 90 days, 58% for 120days.
2) The Plastic limit values are decreases 33% for BC soil, 29.2% for 28 days, 26.8% for 60days, 22.6% for 90 days, 20.5% for 120days.
3) With the increase in curing periods of lime piles the Liquid limit, plastic limit and Plasticity index decreases, which makes the soil less plastic and plasticity index reduces.
4) The Shrinkage limit values are increases in curing periods of lime piles. The Shrinkage limit values are16.36% for BC soil, 17.28% for 28 days, 19.32% for 60days, 20.42% for 90 days, and 22.12% for 120days.
5) With the increases in curing periods of lime piles the Optimum Moisture Content (OMC) is decreases. The OMC values are 26% for BC soil, 24.50% for 28 days, 21.25% for 60days, 20% for 90 days, 18% for 120days.
6) With the increases in curing periods of lime piles the Maximum Dry Density (MDD) is increases. The OMC values are 1.49g/cc for BC soil,1.54 g/cc for 28 days , 1.57 g/cc for 60days,1.62 g/cc for 90 days,1.68g/cc for 120days.
7) The unconfined compressive strength values are increase with increase in curing periods of lime piles. The UCC values are 1.50kg/cm^2 for BC soil,1.58kg/cm^2 for 28days,2.02kg/cm^2 for 60days,2.62kg/cm^2 for 90days, 2.85kg/cm^2 for 120days

The test results indicate changes in the unconfined compressive strength of the of the clay soil treated with lime piles. It was observed that with increasing curing periods of lime piles. The physicochemical improvement in the soil structure caused the clay minerals to form a stronger bond. Formation of the cementitious and pozzolanic reaction products provided better bonding, shearing resistance, and stiffness. This resulted in higher unconfined compressive strength in the treated soils.

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