

A Study on Strength of Clay Soils Treated With Lime-Columns

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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 column 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 columns installed in them. The treated soil block properties were then investigated as a function of lime column 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 column treated soil and produced strong interpartical bonds and unconfined compressive strength of the soil. This is attributed to the migration of Ca^{2+} and Mg^{2+} ions from the lime columns 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 columns, physicochemical reactions, Atterberg limits, OMC and MDD, UCC value.*

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

Allen (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.

Tono reported 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 column–treated soils are dependent on their ionic content, type of lime used, curing time, curing temperature and water content.

Timo (1998) concluded that 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.

Saber and Parches(1979) concluded that the 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, I_p 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 columns as the chemical addition and stability agent to modify the expansive soil. The physical and chemical properties of quicklime are provided in table 2.

Table1. 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
Optimum Moisture Content(OMC)in %	26%
Liquid Limit, LL (%)	78%
Plastic Limit,PL(%)	33%
Plasticity Index, I(%)	45%
UCC value(kg/cm ²)	1.50

Table 2 Chemical and physical properties of the quicklime

PROPERTY	VALUE
Cao (%)	87.20%
Mgo (%)	2.13%
OtherCompounds (%)	9.42%
Loss in Ignition (%)	1.25%
Practical size(μm)	<90

Partical Density (g/cc)	1.15
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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
In situ 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

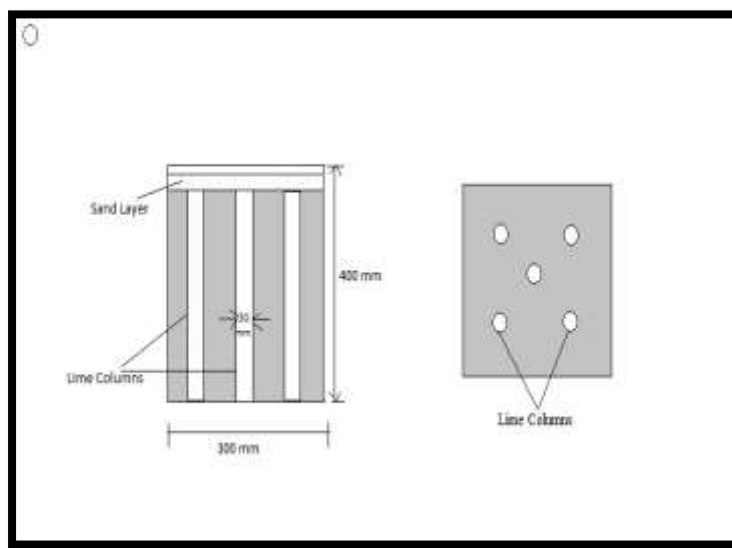


Fig 1 Experimental setup at laboratory

EXPERIMENTAL SETUP

After the lime column 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 columns and to

a) A void a sudden hydration reaction,

b) Minimize the lateral expansion of the lime columns, and

c) Prevent formation of cracks in the soil block.

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 of Lime columns or lime columns are often constructed before the rainy season. During the wet season, the in situ soil and dry lime column are supplied with moisture, which allow migration of cations from the lime into the soil solution. In the laboratory, dry lime and soil block columns absorbed the water, and then the Ca^{2+} and Mg^{2+} ions were allowed to diffuse into the solution from each column.

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 columns for different curing periods: 28, 60, 90 and 120 days.

LIME COLUMN INSTALLATION

It has been shown that prior to the rainy season is the most suitable period for the in situ installation of lime columns and other deep chemical stabilization techniques in arid and semi arid regions of the world. The lime column technique uses the pore fluid to aid physicochemical transfer of cations from the columns 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.



Fig 2 Lime column installation

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 columns. Figure presents the cross-sectional and plan views for distribution of the five lime columns installed within the compacted soil block in the test tank.

SAMPLE EXTRACTION

The sample extraction was conducted at different curing periods within different radial distances to the lime columns 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 columns were extracted from the treated soil within different curing periods to the lime columns in the rectangular test tank are illustrated.



Fig 3 Sample Extraction

5. RESULTS AND ANALYSIS

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

Effect of Lime Column on Liquid limit

The liquid limit of black cotton soil is found to be 78%. The lime column 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 columns 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 120 days, respectively.

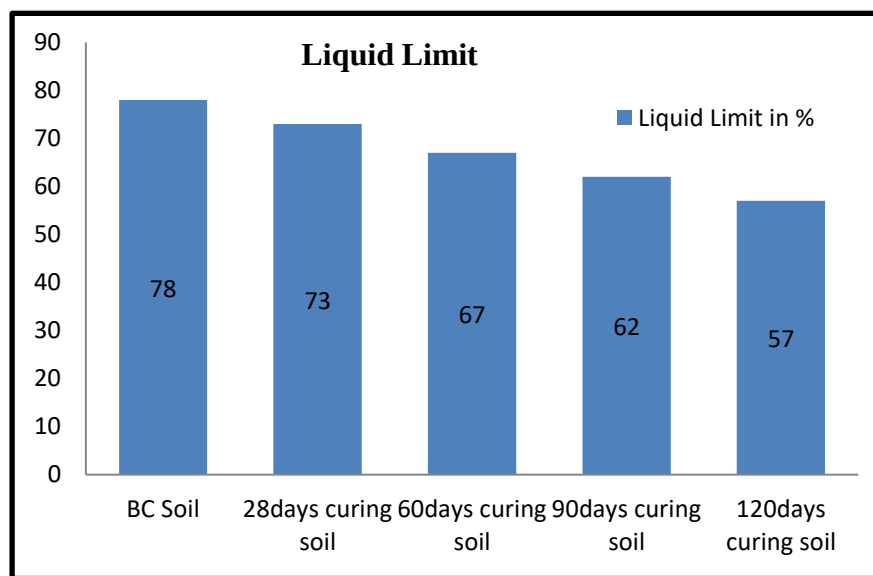


Fig 4 Variation of Liquid Limit with Different curing periods of soil treated with Lime Columns

Effect of Lime column on Plastic limit

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 column 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, 90 and 120 days respectively. The Plasticity Index reduced 45%, 42.8%, 40.6%, 40.2% and 37.5% within curing periods 28, 60, 90, and 120 days.

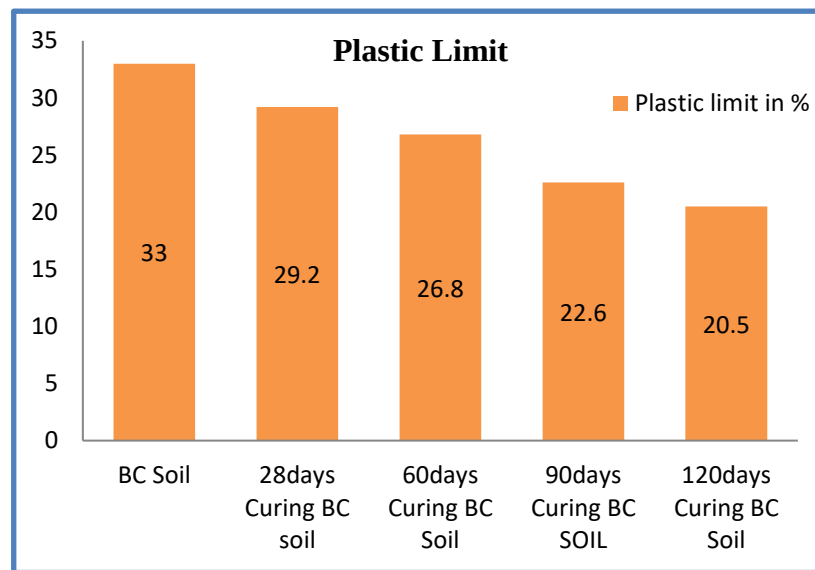


Fig 5 Variation of Plastic Limit with different curing periods of soil treated with Lime Column

Effect of Lime Column On Compaction Properties

The disturbed soil samples extracted from the lime-column 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 be 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 cations 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.

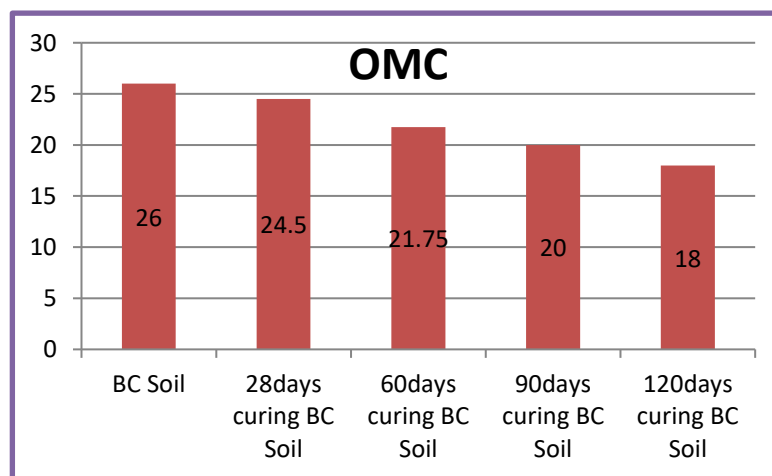


Fig 7 variation of Optimum Moisture Content (OMC) with Different curing periods of Soil treated with Lime Columns

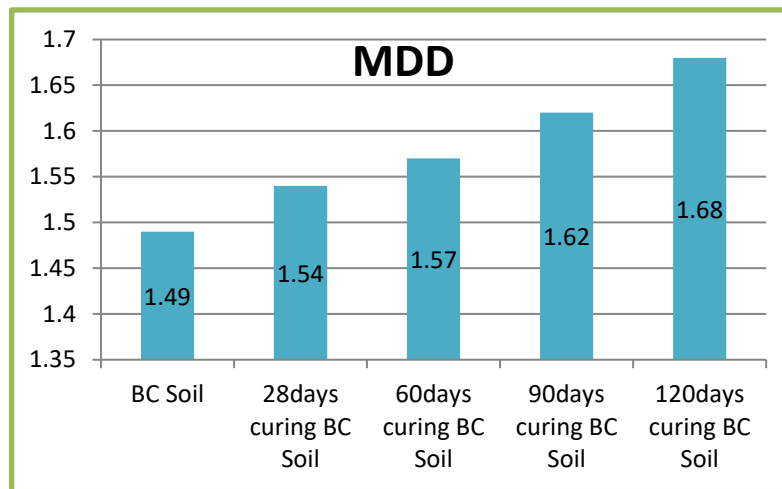


Fig 8 variation of Maximum Dry Density (MDD) with Different curing periods of Soil Treated with Lime Column

Table 4 Variation in Void Ratio at different curing periods

Soil at Different Curing Days	Void Ratio(e)
0	0.79
28	0.48
60	0.44
90	0.33
120	0.19

Void Ratio

$$e = \frac{G_{pw}}{\gamma_d} - 1$$

Where e = Void Ratio, G =Specific

Gravity, ρ_w =Unit Weight, γ_d =Dry

Density

Effect of UCC values on Lime Column

The results of the unconfined compression tests in accordance with on different soil blocks treated with lime columns. 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 columns. 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 column-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 columns with longer curing periods. Test results show that the treated specimens formed a granular-like material. Diffusion of lime from the columns modified the textural, mineralogical, and physicochemical properties of the soil blocks and produced a significant increase in strength, stiffness, and durability.

See Figure 9.

DATA ANALYSIS

The Equations obtained by simple regression analysis are tabulated below, where soil properties as dependent variable

and curing period as independent variable. In the equation “Y” is referred as soil property and “X” as curing Period.

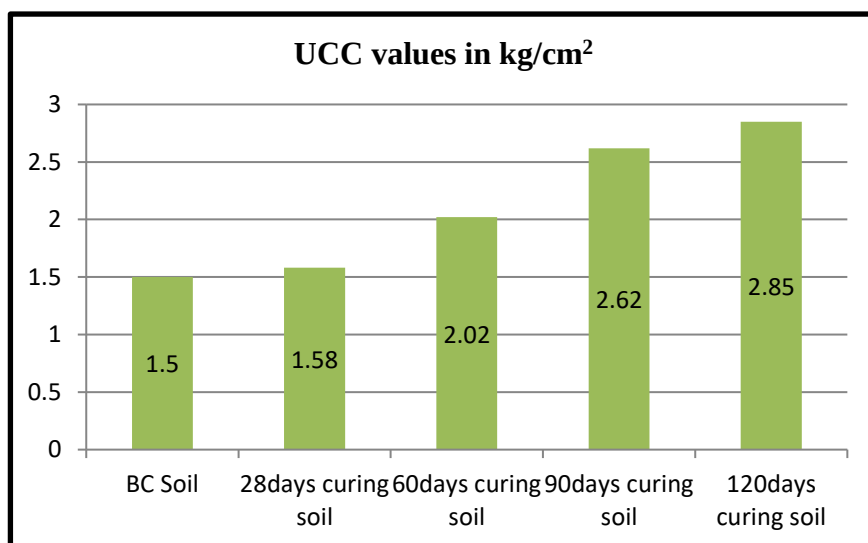


Fig 9 Variation of Unconfined Compression values with Different curing periods of soil treated with Lime Column

Table 5 Relation between Curing period and Soil Properties by Regression Analysis

Soil Properties	Linear Equation	R ² Value
Liquid Limit	$Y = -0.160X + 79.18$	0.996
Plastic Limit	$Y = -0.098X + 32.14$	0.982
OMC	$Y = -0.051X + 26.24$	0.993
MDD	$Y = 0.001X + 1.488$	0.975

UCC

$Y=0.014X+1.193$

0.976

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) It is observed that the Liquid Limit decreased with increase in curing periods the decrease is observed to be “6.41% to 25.64%”.

2) It is observed that the Plastic Limit decreased with increase in curing periods the decrease is observed to be “11.51% to %37.87%”.

Atterberg limits:

Percentage decrease in Atterberg Limits

Curing Periods	28	60	90	120
Liquid Limit (%)	6.41	14.10	19.28	25.64
Plastic Limit (%)	11.51	18.78	31.51	37.87

Regression Analysis:

- The relation between Liquid Limit and Curing period is obtained as “ $Y=-0.160X+77.18$ ”, the R2 value is 0.996.

This indicates a strong correlation between Liquid Limit and curing periods.

- The relation between Plastic Limit and Curing period is obtained as “ $Y=-0.098X+32.14$ ”, the R2 value is 0.982.

This indicates a strong correlation between Plastic Limit and curing periods.

Compaction Properties:

It is observed that the MDD increased with increase in curing periods the increase is observed to be “3.35% to 12.75 %”.

Regression Analysis:

- The relation between MDD and Curing period is obtained as “ $Y=0.001X+1.488$ ”, the R² value is 0.975.

This indicates a strong correlation between MDD and curing periods.

UCS Value:

It is observed that the UCS of increased with increase in curing periods the increase is observed to be “5.33% to 90%”.

Regression Analysis:

- The relation between UCS and Curing period is obtained as “ $Y=0.014X+1.193$ ”, the R² value is 0.976.

This indicates a strong correlation between UCS and curing periods.

Percentage Increase in Compaction properties

Curing Periods	28	60	90	120
Increasing MDD (%)	3.35	5.36	8.72	12.75

Percentage increase in UCS Value

Curing Periods	28	60	90	120
Increasing UCS Value (%)	5.33	34.66	74.66	90

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