Effect of Lime Column on the Geotechnical Properties of Kuttanadu Soil along Radial Direction

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Abstract — *various innovative foundation techniques are being used to stabilize and to improve the properties of the soft soil. Mixing with additives such as lime and cement are widely used and clay soil can be effectively stabilized with the help of lime. The present paper investigates the effect of lime column when installed in soft clay. A single lime column of specific diameter and depth was installed in a steel tank of specific dimensions filled with Kuttanadu clay. Soil sample was collected after specific days of curing from different radial distance from the center of lime column. The samples collected were tested for determining moisture content, UCC strength, liquid limit, plastic limit, shrinkage limit and coefficient of permeability. The value of moisture content and liquid limit decreased with ageing near to the lime column. The value of UCC strength, plastic limit and shrinkage limit increased with ageing near to the lime column. The values of coefficient of permeability initially increased near the lime column and after ageing the values were found to be decreased. The tests show that after the installation of lime column the lime will migrate up to a distance of 3D and with ageing there is alterations in the properties of the soil. As the radial distance increases the values of above properties remain more or less the same value as that of virgin clay.*

Keywords— *Soft Soil, Lime Column, Radial Distance, Moisture Content, UCC strength, Atterbergs limits, coefficient of permeability*

I. INTRODUCTION

Soft clays of low strength and high compressibility are located along the coastal and offshore areas and they cause several foundation problems for the structures founded in these deposits. The availability of land in urban areas for construction purpose has become scarce due to increase in population, urbanization and industrialization. Also, in recent years, the scale of design and construction of infrastructure in the natural soft ground has increased tremendously as a result of extensive urbanization and industrialization. People started using low lying areas and marshy lands for construction of buildings. Soft soil formations with high in-situ water content are susceptible to large settlements and possess low shear strength. Moreover clayey soils have low permeability, consolidation characteristics, and very low shear strength when wet. Due to these properties, the soils show large volume changes due to wetting and drying, breaking up due to freezing and thawing and frost susceptibility, which cause problems in construction field.

Kuttanad is a region in the state of Kerala, India which lies in a depth of 0.6 to 2.2m below the mean sea level. The major portion of this region remains submerged, mostly during the monsoon season. The soil in this region is highly problematic in nature. They possess very low strength, which reduces the ability of the soil to support even light weight structures. Several reports have shown that the structures founded on this soil have undergone severe foundation failure due to shear failure.

There are various methods of modification that are possible to improve the soil properties. Mixing with additives such as lime, fly ash, cement, etc. is widely adopted to improve the properties of soft clay. Clayey soils can be effectively stabilized with the help of lime stabilization. Lime as an additive, has been recognized to bring several beneficial changes in the engineering properties of fine grained soil. When lime is added to soil, certain chemical reaction takes place which attributes to the strength gain of the soil. Stabilization is generally carried out to improve the workability, reduce the plasticity, and increase the strength of a soil. The lime-soil reactions which cause these changes are generally accepted due to the reaction of the calcium ion from the lime, with the silicon (Si) or aluminium (Al), or both, present in the soil to form calcium compounds ([2]). The reaction between lime and clay in the presence of water are Base Exchange, flocculation, carbonation and pozzolonic reaction. Pozzolonic reaction contributes to major gain in strength. Therefore the amount of cementation produced by lime is related to the reactivity and the amount of the pozzolonic material existing in the soil.

After the lime column is installed, the lime reacts with the surrounding soil. As an exothermic reaction, this reaction consumes some amount of water and produces cementation reaction products. In the case of soft soils, water is already present within them which are able to interact with the clay and develop strength. As the hydration process continues the water content around the lime column will decrease. As a result, the soil strength nearby the lime column increases with decreasing water content. Treatment with lime is observed to decrease the soil plasticity and shrink-swell potential and improve the strength characteristics of soils ([5]; [6]; [8]; & [11]).Although the original objective of the soil stabilization was, to increase the strength or stability of the soil, gradually, techniques of soil treatment have been developed until soil stabilization increases or decrease almost every engineering property of soil.

II. MATERIALS

A. Soil

The Soil used for the study was Kuttanad clay collected from Alappuzha district, Kerala. These are dark brown colored deposits. The properties of soil are presented in Table 1. The soil collected was classified as 'MH' as per Indian Standard Classification. The particle size distribution curve of the soil is shown in figure1.

III. TABLE I

INITIAL PROPERTIES OF SOIL

Property	Typical Value
Specific Gravity	2.33
Liquid Limit	125 %
Plastic Limit	38 %
Plasticity Index	87 %
Shrinkage Limit	25.4 %
Hydrometer Analysis:	
Silt (%)	74%
Clay (%)	26 %
IS Classification	MH
Optimum Moisture Content	32 %
Maximum Dry Density	1.27g/cc
Unconfined Compressive Strength	6 KN/m^2
Coefficient of Permeability	2. 240 x 10^{-4}cm/s

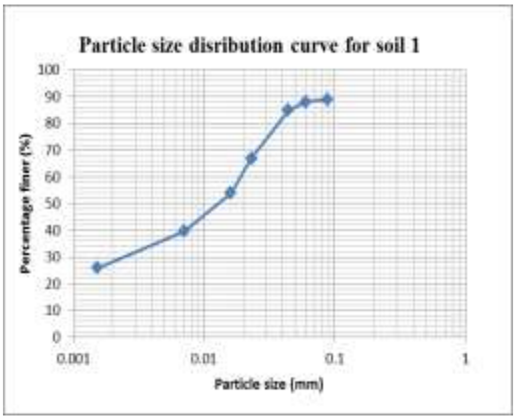

Fig.1 Particle size distribution curve

B. Lime

The commercially available superior grade quick lime was used to prepare lime column. The improvement of the Geotechnical properties of the soil is mainly achieved by two basic chemical reactions. Short-term reactions include cation exchange and flocculation. This results in an increase in the inter particle attraction causing flocculation and aggregation with a subsequent decrease in the plasticity of the soils. Long-term reaction includes pozzolanic reaction, where calcium from the lime reacts with the soluble alumina and silica from the clay in the presence of water to produce stable calcium silicate hydrates (CSH), and calcium aluminate hydrates (CAH), and calcium aluminium silicate hydrates (CASH) which generate long-term strength gain and improve the Geotechnical properties of the soil([1]; [4]; & [9]). The physical and chemical properties of the lime as provided by the manufacturer are presented in Tables 2 and 3 respectively.

IV. TABLE II

PHYSICAL PROPERTIES OF LIME POWDER

Property	Typical Value
Color	White
Specific Gravity	2.365
Dry Density	1.44 g/cc
Bulk Density	3.34 g/cc
Moisture Content	27 %
PH	12.8

V. TABLE III

CHEMICAL PROPERTIES OF LIME POWDER

Components	% Weight
Calcium hydroxide Ca $(OH)_2$	90
Silica	1.5
Ferric oxide	0.5
Magnesium oxide, MgO	1
Alumina	0.2
Carbon dioxide	3

VI. METHODOLOGY

The present experimental program investigates the efficiency of the lime column method to stabilize the Kuttanadu clay. A test tank of 45cm depth and 65 cm diameter was made and Kuttanadu clay was filled into it ensures that no voids are formed. The test set up of the tank is shown in figure2. The soil in the tank was covered with a polyethylene cover and was maintained till uniform consistency was obtained. The uniform consistency was ensured by, collecting samples from different part of the tank and was tested for the water content. The samples were maintained with a water content of 100%.

GI pipe of 20cm height and 5cm diameter was installed into the center of the tank filled with soil and the area within the casing filled with soil was cleaned.

Quicklime was filled into the casing carefully and a slight compaction was carried out using a steel rod. The lime required to fill the casing was 1kg. The column was allowed to cure for specific periods. The samples were taken from a radial distance of 1D, 2D, 3Dand 4D from the center of lime column on 7th, 14th, 28th and 90th day. Collected samples were analyzed for the variation in moisture content UCC strength, Atterbergs limits and coefficient of permeability.

The water content of the samples was determined using the oven drying method according to IS 2720 (Part-2; 1973). The UCC strength of the cured specimens was performed according to IS: 2720-Part 10 (1991). The liquid limit of the soil was determined by Casagrande's method and plastic limit as per Indian Standard Procedure (IS 2720 Part V, 1985). The Shrinkage limit was determined as per the Indian Standard Procedure (IS 2720 Part VI, 1964). The permeability test of the cured specimens was performed according to IS: 2720 (Part-17; 1986) in a variable head permeameter

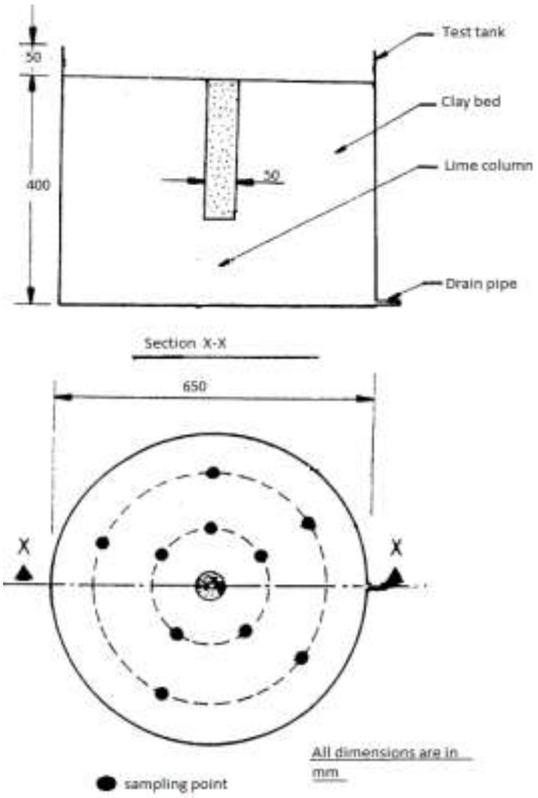

Fig. 1 Experimental setup

VII. Results and Discussion

A. Variation of moisture content

VIII. TABLE IV

Moisture Content After Different Curing Period

Radial distance (cm)	Moisture Content (%)			
	Day7	Day14	Day 28	Day 90
1D	91.55	89.65	85.61	78.0
2D	94.3	92.96	87.22	80.6
3D	98.12	96.18	94.26	82.0
4D	99.6	99.13	98.6	96.5

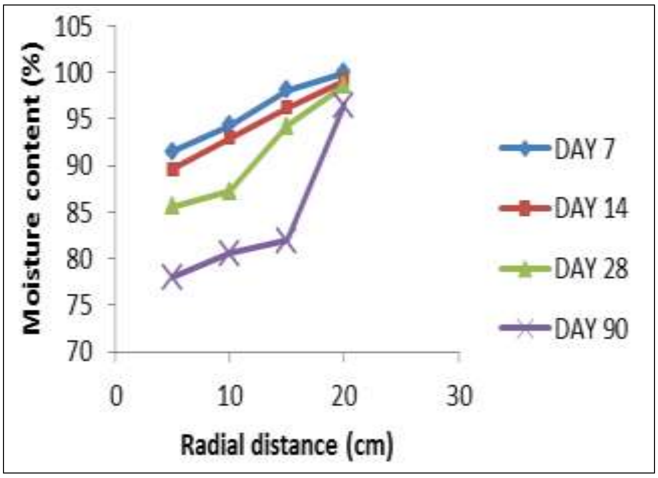

Fig. 3 Variations of moisture content with radial distance

From the moisture content test results, it is found that the moisture content values follow an increasing trend with an increase in radial distance from the center of the lime column, which is less than the virgin clay. A reduced value is obtained in the samples collected adjacent to the lime column. As there is much concentration of lime near to the lime column, moisture content is lesser for the samples collected adjacent to the column, whereas the moisture content is more for the samples collected at a greater distance from the lime column. The reduced value of moisture content is due to the presence of higher concentration of lime at the location adjacent to the lime column, which takes part in pozzolonic reaction and results in the formation of more amount of C-S-H gel near the lime column. It is also observed that as the curing period increases, the moisture content value decreases along the radial distance. Moisture content decreases by 22% at 1D after 90 days of curing. The variation in moisture content is shown in table 4 and figure 3.

B. *Variation of UCC strength*

IX. TABLE V

UCC STRENGTH AFTER DIFFERENT CURING PERIOD

Radial distance (cm)	UCC Strength (kN/m^2)			
	Day7	Day14	Day 28	Day 90
1D	7.7	8.04	9.2	12.06
2D	7.26	7.55	8.29	10.7
3D	6.66	6.92	7.31	9.6
4D	6	6.2	6.36	7.42

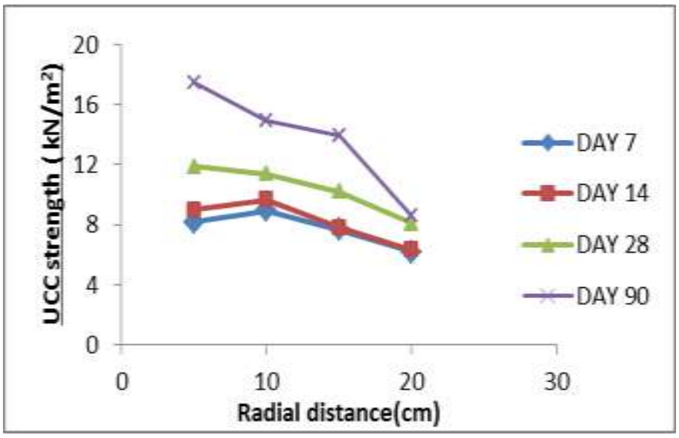

Fig. 4 Variations of UCC strength with radial distance

As the reaction is exothermic the formation of reaction compound consumes water and produces cementation reaction products. In the case of soft soils, water is already present within them which are able to interact with the clay and develop strength. As the hydration process continues with time more amount of reaction products like C-S-H gel are formed near the lime column. As a result, the soil strength nearby the lime column increases with the decreasing water content and ageing. Whereas for the samples collected at a greater distance from lime column, the moisture content and the strength remain the same as that of the virgin clay. The value of UCC strength increases by 101.16% at 1D after 90 days of curing. The variation in UCC strength is shown in table 5 and figure 4.

C. *Variation of liquid limit*

X. TABLE VI

LIQUID LIMIT AFTER DIFFERENT CURING PERIOD

Radial distance (cm)	Liquid limit (%)			
	Day7	Day14	Day 28	Day 90
1D	118	116	115.2	114.8
2D	118.4	117.0	116.4	115.0
3D	122.0	119.8	119.0	117.5
4D	125	124.8	123.6	123.0

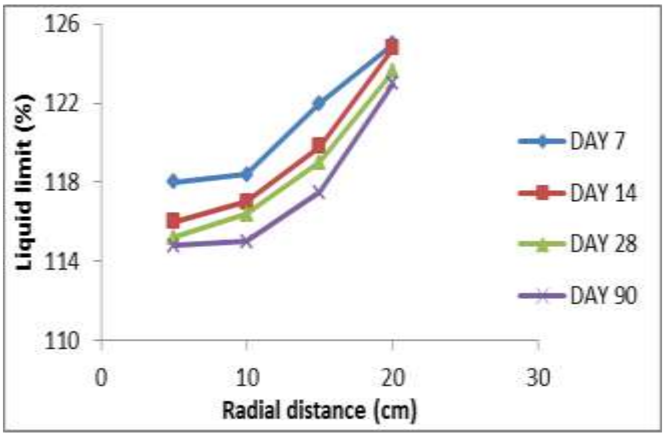

Fig. 5 Variations of liquid limit with radial distance

From the liquid limit test results, it is found that the liquid limit values follow an increasing trend with an increase in radial distance from the center of the lime column, which is less than the virgin clay. A reduced value is obtained in the samples collected adjacent to the lime column and a higher value for the samples collected from a greater distance. When lime reacts with soil, it releases the bond between the soil particles, thus decreasing the value of soil cohesion. As a result the amount of water required will be less to achieve the liquid limit. As the radial distance increases the value of liquid limit also slightly increases due to lesser migration of lime. Also, as the ageing increases the value of liquid limit nearer to the lime column decreases. The decrease in value of liquid limit is effective up to day 14, after which the decrease is lesser. The migration of lime is effective for a distance of 3D from the center of lime column. The value of liquid limit decreases by 8.16% at 1D after 90 days of curing. The variation in liquid limit is shown in table 6and figure 5.

D. *Variation of plastic limit*

XI. TABLE VII

PLASTIC LIMIT AFTER DIFFERENT CURING PERIOD

Radial distance (cm)	Plastic limit (%)			
	Day7	Day14	Day 28	Day 90
1D	43.7	46.44	48.33	50.60
2D	42.0	44.13	46.0	46.51
3D	40.1	41.6	42.90	42.67
4D	38.0	38.20	38.22	38.38

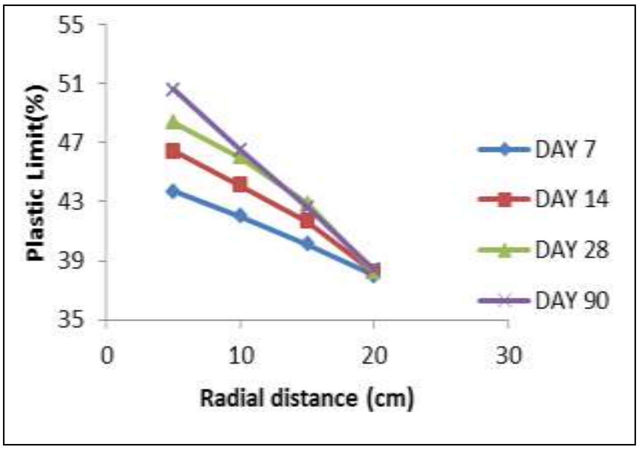

Fig. 6 Variations of plastic limit with radial distance

From the plastic limit test results, it is found that the plastic limit values follow a decreasing trend with an increase in radial distance from the center of the lime column, which is less than the virgin clay. The value of plastic limit obtained from the samples collected adjacent to the lime column is more than the samples collected from a greater distance. The increase in plastic limit is due to the decrease in moisture content for the samples collected adjacent to the lime column, causing a decrease in the value of soil cohesion. As the radial distance increases the value of plastic limit slightly decreases due to lesser migration of lime. Also, as the ageing increases the value of plastic limit nearer to the lime column increases. The increase in value of plastic limit is effective up to day 14, after which the increase is lesser. The migration of lime is effective for a distance of 3D from the center of lime column. The value of plastic limit increases by 38.42% at 1D after 90 days of curing. The variation in plastic limit is shown in table 7 and figure 6.

E. *Variation of shrinkage limit*

XII. TABLE VIII

SHRINKAGE LIMIT AFTER DIFFERENT CURING PERIOD

Radial distance (cm)	Shrinkage limit (%)			
	Day7	Day14	Day 28	Day 90
1D	29.64	33.36	35.5	39.198
2D	27.8	30.425	32.673	34.21
3D	26.55	27.36	29.496	30.89
4D	25.94	26.010	26.64	27.328

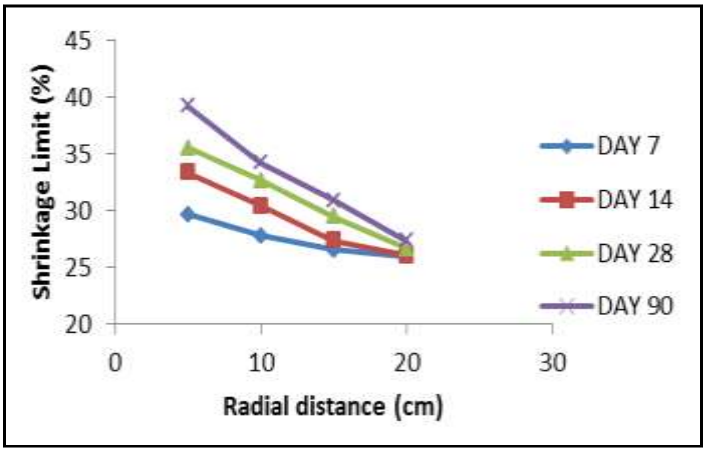

Fig. 7 Variations of shrinkage limit with radial distance

From the shrinkage limit test results, it is found that the shrinkage limit values follow a decreasing trend with an increase in radial distance from the center of the lime column, which is less than the virgin clay. The value of shrinkage limit obtained from the samples collected adjacent to the lime column is more than the samples collected from a greater distance. The greater is the shrinkage limit, then lesser will be the tendency of the soil to expand. Increase in shrinkage limit is because of hardening of the soil, which decreases the water absorption capacity of the treated soil. As the radial distance increases the value of plastic limit slightly decreases due to lesser migration of lime. The value of shrinkage limit increases with ageing considerably up to day 14 and after which the increase in value is less. The value of shrinkage limit increases by 70% at 1D after 90 days of curing. The variation in shrinkage limit is shown in table 8 and figure 7.

F. *Variation of coefficient of permeability*

XIII. TABLE IX

COEFFICIENT OF PERMEABILITY AFTER DIFFERENT CURING PERIOD

Radial distance (cm)	Coefficient of permeability (cm/s)			
	Day7	Day14	Day 28	Day 90
1D	2.640×10^{-4}	2.920×10^{-4}	2.882×10^{-4}	2.585×10^{-4}
2D	2.488×10^{-4}	2.567×10^{-4}	2.525×10^{-4}	2.310×10^{-4}
3D	2.273×10^{-4}	2.448×10^{-4}	2.200×10^{-4}	2.268×10^{-4}
4D	2.243×10^{-4}	2.268×10^{-4}	2.259×10^{-4}	2.248×10^{-4}

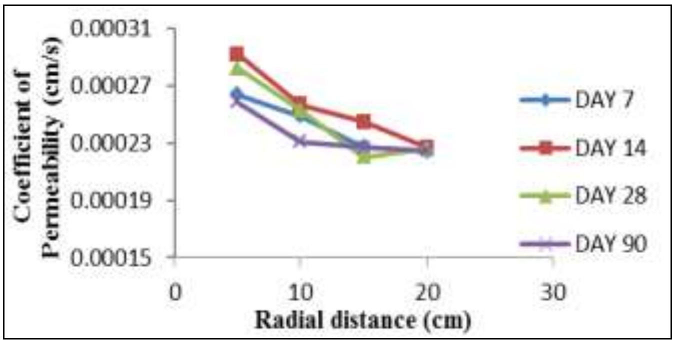

Fig. 8 Variations of coefficient of permeability with radial distance

From the permeability test results, it is found that the coefficient of permeability follows a decreasing trend with an increase in radial distance from the center of the lime column, which is less than the virgin clay. Higher value of permeability is obtained for the samples collected adjacent to the lime column and a lesser value for the samples collected from a greater distance due to lesser migration of lime. The higher value of permeability is achieved due to hydration and flocculation. Hydration causes the expansion of the lime which enhances the rate of consolidation. As the rate of consolidation increases coefficient of permeability also increases. Flocculation results in the formation of pores in the soil, thereby making pathways for the quick drainage of water. As the curing period increases the K value decreases due to the participation of lime in pozolonic reaction and due to the formation of products like CSH gel which causes reduction in the void space and the interconnectivity of pore channels. Increase in permeability is observed up to day 14 and after which the K value decreases. The variation in the coefficient of permeability is shown in table 9 and figure 8.

V. CONCLUSIONS

The following conclusions can be drawn from the above study;

1. Migration of lime takes place up to a distance of 3D from the center of lime column.
2. The moisture content is less near the lime column and it decreases with curing period. . Moisture content decreases by 22% at 1D after 90 days of curing.
3. UCC strength is more near the lime column and it increases with curing period. The value of UCC strength increases by 101.16% at 1D after 90 days of curing.
4. Liquid limit is less near the lime column and it decreases with curing. The decrease in liquid limit is effective up to 14 days of curing. The value of liquid limit decreases by 8.16% at 1D after 90 days of curing.
5. Plastic limit is more near the lime column and it increases with curing. The increase in plastic limit is effective up to 14 days of curing. The value of plastic limit increases by 38.42% at 1D after 90 days of curing.
6. Shrinkage limit is more near the lime column and it increases with curing. The increase in shrinkage limit is effective up to 14 days of curing. The value of shrinkage limit increases by 70% at 1D after 90 days of curing.
7. Coefficient of permeability is more near the lime column initially and then decreases with curing near the lime column.
8. Migration of lime takes place for a lesser distance due to low coefficient of permeability of virgin clay.

Thus, the in-place stabilization by lime column technique has been found to be effective in reducing the moisture content and increasing the strength of Kuttanadu clay deposits in addition to modifying other Geotechnical parameters.

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