Effect of Organic Matter on the Geotechnical Properties of Soil and Impact of Lime-Salt Stabilization in Strength Improvement of Organic Soil

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***Abstract*— Organic clays are considered to be problematic soils in the geotechnical point of view. Their engineering properties are inferior to those of other soils. They are characterized with the presence of different organic matter content, texture and highly variable chemical composition. Hence they possess high compressibility, high settlements and unsatisfactory strength characteristics. Difficulties may arise while implementing conventional methods of improvement which are successful in other soft soils. A number of embankment and approach road failures have been noted down in Kuttanadu region, Kerala, due to high organic nature of the soil. A geotechnical investigation is done to analyse the inverse effect of organic matter on the soil properties in natural state itself. Methodology consists of collecting samples from the region with different range of organic content and laboratory testing to evaluate its engineering properties. Empirical correlations are formulated to predict the liquid limit and plastic limit of organic clay under study in terms of its amount organic content. Investigation and interpretation of the influence of organic content on the settlement behaviour of organic clay is done.**

Keywords*— Organic content, Atterberg limits, Coefficient of consolidation, Compression index, Void ratio

I. INTRODUCTION

The plant debris, litter in various forms and the materials in the form of humus present in soil is collectively called soil organic matter. The phytomass which is the vegetation growth in soil is excluded from this group of organic matter. Carbon containing materials which are living or dead is specified as organic content of soil. Organic matter is generated when the rate of formation exceed their rate of decay. The organic wastes which are getting deposited into the soil as a result of rapidly growing industrialization is also considered to be a major source of organic matter in soil. Humic acid and fulvic acids are the major constituents of organic matter. Very dark residue formed from the soil on the action of strong reagent with the soil is known as humic acid. These are formed by acidic groups such as phenolic or carboxylic groups.

The microorganisms in the soil derive their energy for sustainability by the oxidative decomposition of organic matter. This decomposition process is the breakage of complex compound into simple forms through any biological or chemical reactions. After the decay these immobilized molecules are released as carbon dioxide leaving their spaces empty. These scenario leads to the rearrangement of soil particles which is referred as settlement. Hence organic soils are considered to be problematic soils because of this high settlement rate and low shear strength values.

The organic matter in the soil is collectively termed as soil organic matter (SOM). This SOM plays a major role in defining the physical and chemical properties as well as the soil capacity. This high organic content will make the soil structure very weak and some sort of stabilization may require improving the capacity of soil and thereby making it suitable for any construction purpose. Since the strength and compression behaviour of organic soil is appeared to be inferior to those of other soft clays, it is of great interest to concentrate on the effect of soil organic matter on the engineering and index properties of organic soil.

II. MATERIALS AND METHODOLOGY

A. Materials

1) Soil: Four Samples with different organic content were collected from river bed of Kuttanadu region in Aleppy district of Kerala, India. The samples were obtained from a depth of 2 m below the river bed and were located at a minimum distance of 300 m apart. Samples are classified as organic clay of high plasticity (OH) according to IS 1498 (Part 1) - 1987. To keep the organic content unaltered, natural state of the samples are maintained in such a way that no air drying have been allowed.

2) Oxidising agent: Hydrogen Peroxide(20%) is used as the oxidizing agent for organic content determination.

3) Inorganic soil: For the study of effect of organic content in salt added lime stabilization inorganic clay is collected from Trivandrum. Initial properties of same are listed below in Table 1.

TABLE 1. INITIAL PROPERTIES OF INORGANIC SOIL

Water Content (%)	Specific Gravity	Clay (%)	Silt (%)	Sand (%)	Liquid Limi	Plastic Limit	Shrinkage Limit	Plasticity Index	Optimim Moisture Content	Max. Dry Density	IS Soil Classification
19	2.41	77	21.3	1.7	64	34	30	32	25.2	1.46	CH

4) Organic material: Organic content is artificially induced into the inorganic soil by mixing it with urea. Amount of organic matter in the urea is identfied as 95% by conducting hydrogen peroxide oxidation test on urea added inorganic soil.

5) Salt: Calcium chloride ($CaCl_2$) is used for improving the effect of lime stabilization in the study.

6) Lime: Properties of lime used for the study on stabilization of organic soil are shown in Table 2.

TABLE 2. PROPERTIES OF LIME

Component	Calcium hydroxide (Ca $(OH)_2$	Silica	Ferric oxide	Magnesium oxide (MgO)	Alumina	Carbondioxide
Amount(%)	90	1.5	0.5	1.0	0.2	3.0

B. Methodology

The hydrogen peroxide (H_20_2-20%) oxidation method was employed immediately on the collected samples to determine organic content of soil. Soil organic matter content varied from 32% to 41%. Natural moisture content of the samples was determined as per IS: 2720 Part 2.

All the laboratory experiments were performed on samples in natural state itself without any prior air or oven drying. Grain size distribution for samples were obtained using hydrometer analysis and wet sieve analysis in accordance with IS 2720 part 4: 1985. One-dimensional consolidation tests as per IS 2720 part 15: 1986 and unconfined compression tests as per IS 2720 Part 10- 1973 were performed. Initially the natural samples were not taking any load at all because of higher water content. Hence 3 days of air drying is done prior testing. Along with water content reduction in organic content is also observed due to the exposure to air followed by oxidation.

Artificial organic soil sample are obtained by mixing air dried inorganic soil with urea crystals. Compaction tests are performed according to IS 2720 Part 6: 1980. To this artificially prepared organic soil sample, lime is added at different percentage at their optimum moisture content and unconfined compression tests were performed and optimum lime content (OLC) is obtained. Along with this OLC, salt is added in different percentage and its effect in strength has been noted down. According to IS 2720 Part 26: 1997 , pH tests of the lime treated soil samples are performed.

III. RESULTS AND DISCUSSIONS

A. Index Properties of Organic Soil Samples

1) Variation of water holding capacity with Organic Content: A direct relationship is observed between percentage of organic matter and water content (Fig.1). Organic composts with high organic carbon and micronutrient content impart high water holding capacity to the soil (L.C. Ram and R.E. Masto, 2014).

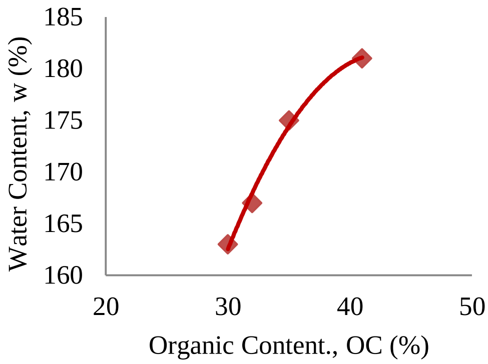

Fig.1. Variation of natural water content with organic content

2) Variation of Grain Size Distribution with Organic Content: Particle size analysis results are shown in Fig. 2.Clay content decreases from 34% to 29% when the percentage of organic matter increases from 32% to 41% which implies that organic content in soil affects its gradation.

Reason for this is the soil aggregation property of organic matter due to its binding nature. This is in accordance with the result that organic matter can induce aggregation on soil particle and thereby a reduction in fine particle fraction is possible [2].

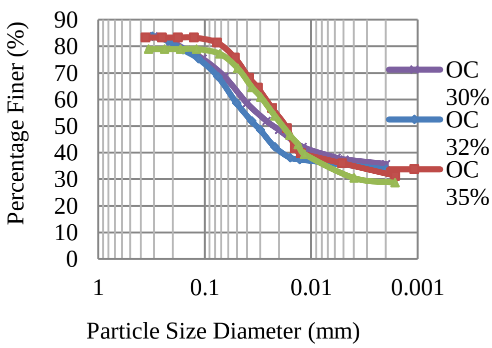

Fig.2. Grain size distribution curves of different organic soil samples

3) Variation of Specific Gravity with Organic Content: Specific gravity of the samples was found to be in the range of 2.12 to 2.48 and the variation of specific gravity of different samples with amount of organic matter is shown in Fig. 3.

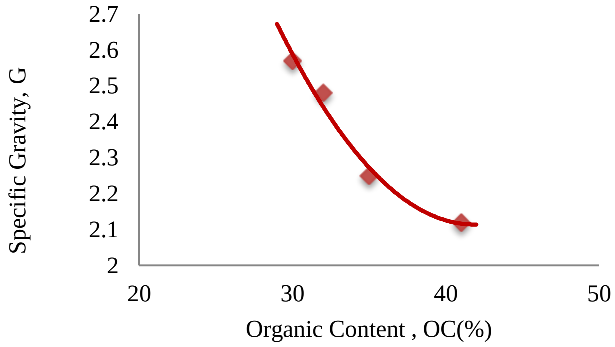

Fig.3. Variation of specific gravity with organic content for different samples

Specific gravity is decreasing non-linearly with increase in organic content. The organic matter is comparatively light in weight with respect to soil particles. As these light organic matters occupies considerable portion of unit volume of soil, highly organic soil possess lesser specific gravity. Amount of light weight organic matter present in compost amended organic soil yields low specific gravity values [1].

4) Variation of Index properties with Organic Content: Variation of liquid limit and plastic limit with organic content are shown in Fig. 4 and Fig. 5 respectively. Both values are found to be increasing linearly with increase in organic content in the soil.

The relationship of liquid limit (LL) of Kuttanadu clay from river bed and organic content (OC) can be represented by the equation (1) with correlation coefficient of 0.998. Similarly equation (2) shows the relationship of plastic limit (PL) of same clay and organic content (OC) with correlation coefficient of 0.998.

$$LL=1.456\ OC+84.5 \qquad (1)$$

$$PL=0.894\ OC+52.36 \qquad (2)$$

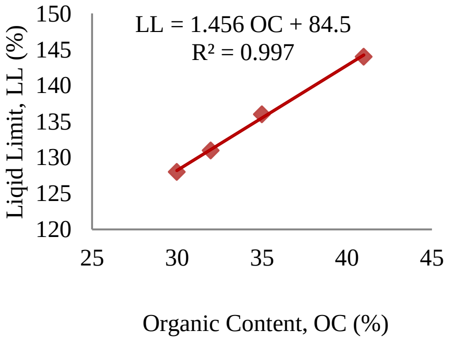

Fig.4. Variation of liquid limit with organic content for different samples

Organic matter induced higher water holding capacity and organic matter induced soil particle aggregation are the main two factors which affects the plasticity characteristics of organic soil [2].High water holding capacity causes the organic matter bonded soil particles to behave like plastic or liquid at high moisture level.

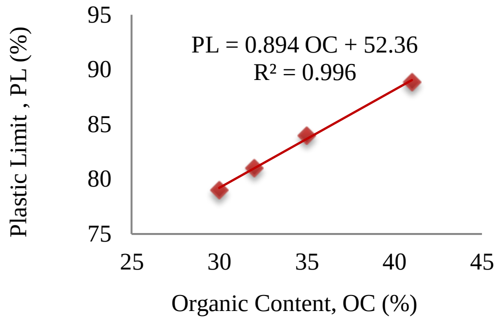

Fig.5. Variation of plastic limit with organic content for different samples

Variation of plasticity index of Kuttanadu clay with organic content in soil samples are given in Fig. 5. Non-linear increase is noted down in plasticity index with increase in organic content.

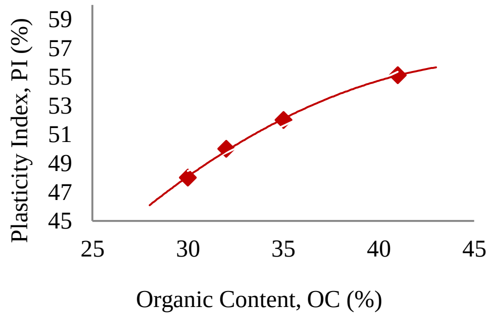

Fig.6. Variation of plasticity index with organic content for different samples

Fig.6 shows the linear increase of shrinkage limit with increase in organic content. As the organic content is higher water holding capacity will be more. Thus more water will be needed to get saturated resulting in increasing the shrinkage limit. Even then the rate of variation remains

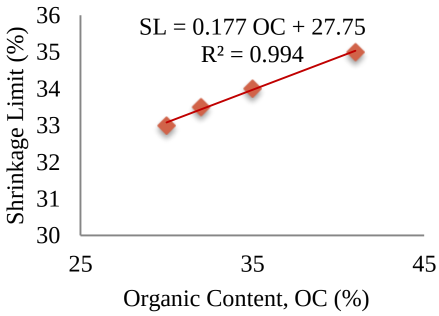

Fig.7. Variation of Shrinkage limit with organic content for different samples

B. Consolidation Behaviour of Organic Soil Samples

Parameters like coefficient of primary consolidation (C_V) and compression index (C_C) are used to assess the effect of organic content on settlement behaviour of Kuttanadu clay. Variation of C_v with organic content is shown in Fig. 7. C_v decreases with increase in organic content in the soil sample and the relation among C_v (m^2/sec) and percentage of organic matter, OC (%) is represented by equation (3) with correlation coefficient of 0.978.

$$C_v \times 10^{-8} = 43.73\ e^{-0.05\ OC} \qquad (3)$$

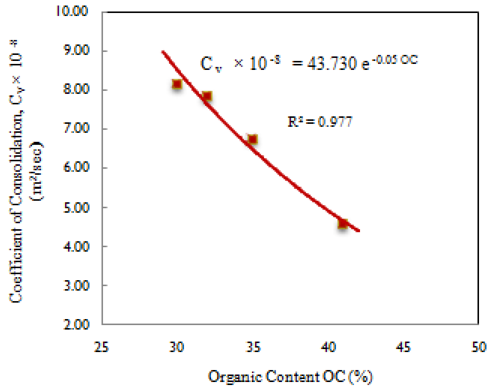

Fig.8. Variation of coefficient of consolidation (C_V) with organic content for different samples

Void ratio plays a major role in the rate of consolidation of organic soil. Variation of void ratio is shown in Fig. 8 and it is seen that void ratio is higher for soil sample with high organic content.

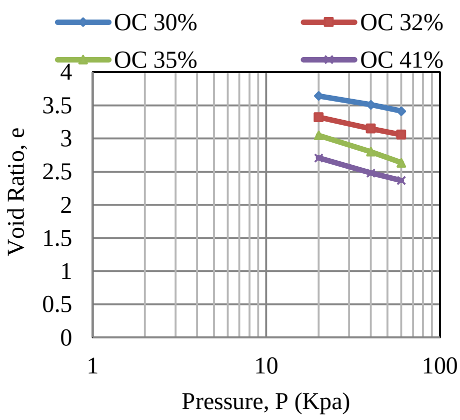

Fig 9. e – log P curves for Kuttanadu clay with different organic content

C_c increases with increase in organic matter in the soil(parabolic variation) and the variation of Cc with percentage of organic content (OC) is shown in Fig.9. As the settlement is directly dependant on the value of C_C settlement will also be more as the amount of organic matter is higher. Relationship among C_c and OC is given by equation 4 with correlation coefficient of 0.997.

$$C_C = -0.004\ (OC)^2 + 0.363\ OC - 6.316 \qquad (4)$$

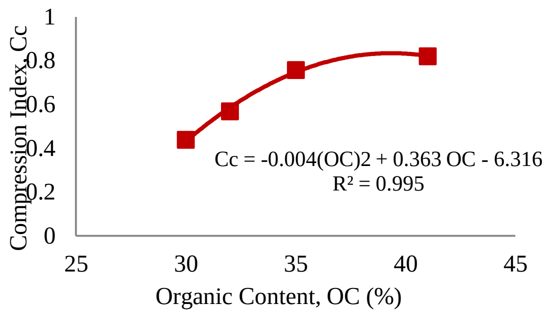

Fig.10. Variation of compression index (C_c) with organic content for different samples

More voids are generated as the organic matter in the soil is degraded on oxidation. Thus the organic soil easily gets settled on rearrangement of soil particles.

C. Shear Strength Characteristic of Organic Soil Samples

Maximum compressive stress is higher for sample with lower organic content. Fig.10 indicates the parabolic decrease of unconfined compressive strength values of samples with increasing organic content. Rate of degradation will be increasing with increment in amount of organic matter resulting into reduction in strength of the soil. . Relationship among UCS value (kPa) and percentage of organic content, OC(%) is given by equation 5 with correlation coefficient of 0.999.

$$UCS = 0.030\ (OC)^2 - 2.371\ OC + 53.59 \qquad (5)$$

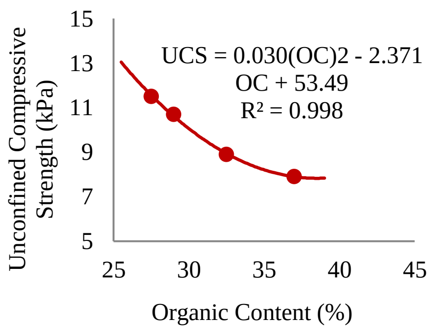

Fig.11. Variation of unconfined compressive strength with organic content for different samples

Axial stress and axial strain were observed to be dependant up on the amount of organic matter. Fig.11 shows that failure strain increases as the amount of organic matter increases. Maximum axial stress was found to be higher for soil sample with lesser amount of organic matter.

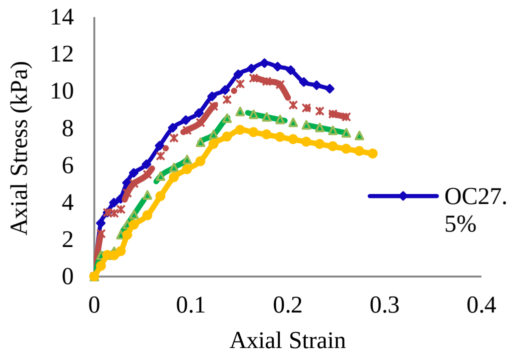

Fig.12. Stress-strain curves for Kuttanadu clay with different organic content

D. Lime Stabilization of Natural Organic Soil

On addition with lime in different percentage, two samples with different percentage of organic amount (23% and 31%) in its natural state showed optimum lime content of 5%. Variation of unconfined compressive strength (UCS) with different amount of added lime is shown in Fig. 12.

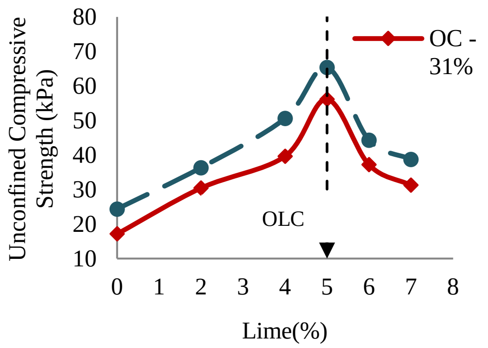

Fig.13. Effect of Lime content on the undrained compressive strength of natural organic soil after 7 days of curing

Impact of lime stabilization in strength with time has been represented in Fig. 13. On addition with lime, UCS value increased up to 28 days and then it started decreasing.

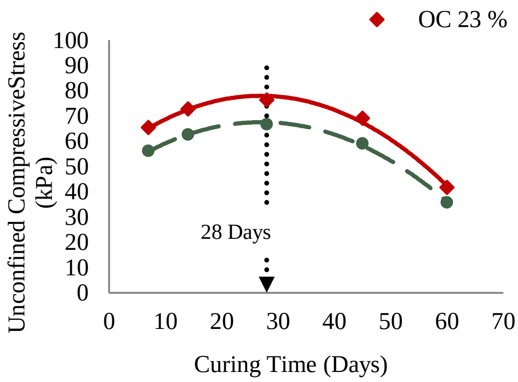

Fig.14. Effect of curing time on the undrained compressive strength of Lime-treated soil

Minimum pH of 12.4 is needed for the proper cementation process to take place [3]. As the time increases organic acids present in the soil will cause the reduction of minimum pH value and ultimately the UCS value will start decreasing. The pH value can be maintained greater than the minimum value required by adding salts along with lime added soil.

E. Salt added Lime Stabilization of Artficial Organic Soil

Optimum lime content of 5% is obtained by adding lime in varying percentage to artificially prepared soil and the variation of UCS with different amount of lime is shown in Fig. 14.

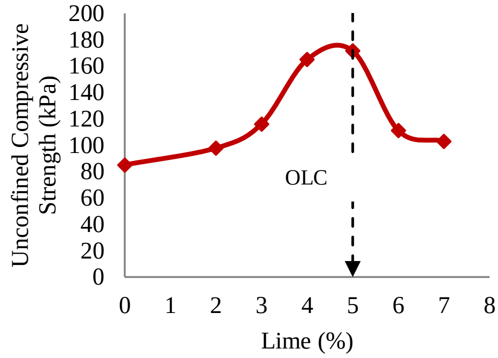

Fig.15. Effect of Lime content on the undrained compressive strength of artificial organic soil after 3 days of curing.

Fig.15 shows the improvement in unconfined compressive strength value on addition with calcium chloride in different percentage to the lime stabilized organic soil.

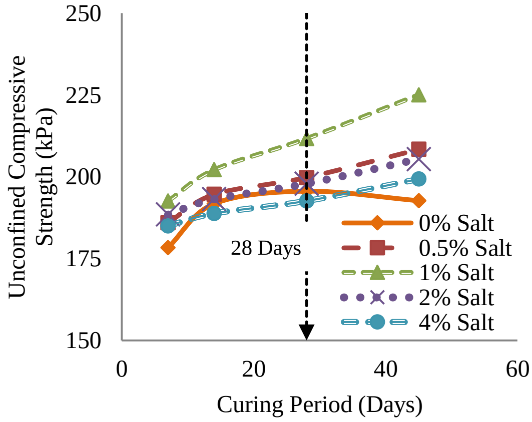

Fig.16. Effect of salt ($CaCl_2$) content on the undrained compressive strength of Lime treated artificial organic soil at different curing period

Without adding any salt along with lime, organic soil shows reduction in unconfined compressive strength after 28 days. Lowering of pH value on the presence of acids in organic soil is quiet compromised by the added salt. It is shown that on addition with salt no reduction in unconfined compressive strength has been reported. More than 1% salt did not much improvement in strength gain

pH of tested unconfined compression tested samples is shown in Fig. 16.

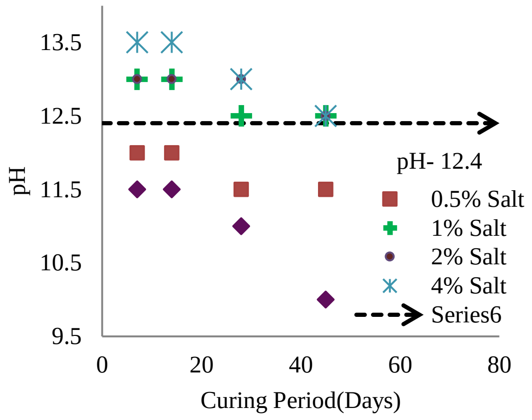

Fig.17. Effect of salt ($CaCl_2$) content on the pH of Lime treated artificial organic soil at different curing period

It has been clear that addition of salt 1% and more maintained a pH value greater than the minimum required. pH is decreasing tremendously for lime treated organic soil in the absence of salt. This is the ultimate reason behind lowering of strength of lime stabilized organic soil.

IV. CONCLUSION

Laboratory studies performed on collected organic soil samples shows that index properties, compressibility characteristics and shear strength behavior is significantly altered by the presence of organic matter. Since the study is done on soil samples preserved in natural state without drying, structural changes to the soil particles are minimized and more accurate results could be obtained. Following points are drawn on the basis of geotechnical investigation performed on organic soil.

- Water holding capacity of soil is directly and non-linearly related to organic content in a soil. Water absorptive power of soil organic matter compared to soil grains is considered to be the reason behind this.
- A dependency of clay fraction on organic content is observed. Organic matter binds together the clay particles of the soil mass as a result of which clay fraction is found to decreasing with increase in amount of organic matter.
- A significant direct linear relationship is shown by liquid Limit and plastic Limit. Only a slight increase in Shrinkage Limit is observed with increase in organic content.
- A direct non-linear relation exists between Plasticity Index and organic content.
- Significant non linear reduction in Specific Gravity is seen in highly organic soil. Compared to heavy soil grains, amount of light weight organic matter present in soil leads to low specific gravity values.
- Coefficient of consolidation, C_v is decreasing exponentially with organic content while compression index, C_c is increasing parabolically with organic content. Magnitude of Settlement will increase with increase in due to increase in C_C
- An increase in void ratio is observed with increase in organic content. Stress-strain behavior is found to be dependent on organic content and stress level and maximum compressive stress is higher for sample with less organic content. Failure strain increases slightly with organic content
- Unconfined compressive strength shows a parabolic reduction with increase in organic content. For 10 % increase in organic content, nearly 31% UCS has been reduced.
- In lime treated natural organic soil, on 60 days of curing, approximately 45% reduction in improvement ratio has been noted down compared to 28 days of curing. Thus it is proved that efficiency of lime treatment in organic soil is poor in long term strength improvement.
- Salt addition along with lime treatment in the organic soil overcomes the drawback of lime addition alone because added salt will maintain the minimum pH value required for the cementing action.
- Potential amount of 1% of calcium chloride has been obtained in improving strength of organic soil.
- Empirical correlations are formulated using regression analysis using which the index properties, consolidation parameters and unconfined compression strength values of organic Kuttanadu soil in terms of amount of organic content can be predicted.

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