Stabilization of Soil using Lime

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Abstract— *Soils erode under small seepage velocity leading to problems of stability of earth and earth retaining structures. The extent of erosion depends on mineralogy and clay chemistry as well as the dissolved salts of the pore fluid. Soil erosion is mainly due to the presence of exchangeable sodium present in the structure. The attractive forces are less than the repulsive forces under saturated conditions and this will help the particle to segregate and to move in suspension. The use of lime to bind the soil clay particles and reduce the erosion and improve the strength of soil has been studied. It has been shown that lime can improve the strength of the soil. Further about 3 percent of lime is found to be optimum. The rate of improvement of strength is fast for the first three days and gradual with further curing up to 14 days. The Young's modulus of the soil also increases with the addition of lime and with curing. There is a good correlation between the unconfined compressive strength and Young's modulus for stabilized soils.*

Keywords— Lime, Unconfined Compressive Strength, Young's Modulus

I. INTRODUCTION

In the past, when soils with good engineering properties such as low plasticity, high bearing capacity, low settlements etc were not available for the construction of embankments, highways, airport runways, dams and other earthen infrastructure the ease of construction and ease in procuring the materials were the factors that governed the choice of site rather than economic factors. But at present, due to increased land use pattern there is more concern about the economy. In practice, soils with low bearing capacity, low stability, high settlements, excessive swelling or shrinkage properties are usually encountered. It has become necessary to make such soils suitable for construction by increasing the strength, reducing compressibility, swelling or shrinkage and increasing the durability of soils by altering the properties. In this direction, soil stabilization is very promising and in particular lime stabilization is generally adopted in the field of highways and construction of earthen infrastructure due to its cost advantage and several beneficial changes in the engineering properties of soils such as improvement in plasticity and strength, decrease in shrink swell potential. The strength of the clayey soil increases with increase in lime content up to certain limit, called optimum lime content which depends on clay content and reactive silica. It is observed that the lime treatment reduces the settlement and improves the strength and is useful in problematic soils. Brandl (1973) has adopted deep in-situ method of lime stabilization in the form of lime columns to stabilize slopes in Austria. Broms and Boman (1975) used lime columns to stabilize clays. Okumara and Terashi (1975) have used lime column method to stabilize thick soft marine clay deposits in a Japanese harbor area. Balasubramaniam et al (1989) have adopted quicklime for the stabilization of soft Bangkok clays. They observed that unconfined compressive strength increased nearly ten times by the addition of 5 percent lime.

II. MEHANISM OF LIME STABILIZATION

Stabilization of soil by lime is achieved through cation exchange, flocculation, agglomeration, lime carbonation and pozzolanic reaction. Cation exchange, flocculation and agglomeration reactions takes place rapidly and bring immediate changes in soil properties such as strength, plasticity and workability(Bell 1988), whereas, pozzolanic reactions are time dependent. These pozzolanic reactions involve interactions between soil silica and/or alumina and lime to form various types of cementatious products thus enhancing the strength.

The chemical interaction plays an important role in the lime stabilizations of soils. The following four basic reactions take place when lime is added to soil:

(1) Cation exchange

$$Ca^{++} + Clay \rightarrow Ca^{++}Clay + (Na^{+}, K^{+}) \quad (1)$$

(2) Flocculation/Agglomaration

(3) Carbonation

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \quad (2)$$

(4) Pozzolanic reactions

$$Ca^{++} + 2(OH)^{-} + Si_2O_2 \rightarrow CSH \quad (3)$$

$$Ca^{++} + 2(OH)^{-} + Al_2O_3 \rightarrow CAH \quad (4)$$

The cation exchange starts to take place between the metallic ions associated with the surface of the clay particles and that are surrounded by a diffuse hydrous double layer, which is modified by the ion exchange of calcium, because of which there is alteration in the density of the electrical charge around the clay particles, that leads to the flocculation of particles. This process is mainly responsible for the modification of the engineering properties of clay soils treated with lime (Bell 1996).

The carbonation reactions are generally undesirable because it gives weak cementing agents. The pozzolanic reaction is time dependent and it is mainly responsible for improvement in soil properties. The long term physico-chemical changes are due to pozzolanic reactions. The pozzolanic reactions are facilitated by the lime creating highly alkaline soil pore chemistry. This promotes dissolution of silicon and aluminium from the clay. The dissolved components react with the calcium ions present in the pore water forming calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH). These compounds crystallize with time that results in changes in clay plasticity, increase in shear strength and reduction in permeability (Boardman et al 2001).

III. MATERIALS AND EXPERIMENTAL METHODS

The study deals with stabilization of soil called Suddha soil that is present in Southern parts of Karnataka, India. It is wide spread below a depth of 1.5 m from the ground level and extends to depths greater than 10 m. It possesses good strength in dry condition and upon increase in moisture content looses strength. Many failures have been observed along canal slopes, road bases and foundations at sites where this soil is present. For the present study Suddha soil (silty soil) was collected from Hemavathi Canal Zone, near Tumkur, from locations where canal side slopes had failed.. It has sand as the major constituent followed by silt and clay with the group symbol SC. It has liquid limit of 41 and plasticity index of 17.

Chemically pure lime obtained from standard manufacturers is used as stabilizing agent. The concentrations of lime used are 1, 2 and 3 percent by dry weight. The experiments were conducted to determine the Atterberg's limits, compaction characteristics and unconfined compressive strength. The tests were carried out as per relevant IS codes of practice and standards.

The soil collected from the site was pulverized with a wooden mallet to break lumps and then air-dried. It was then sieved through 2.00 mm IS sieve and then dried in an oven at 105^0 C for 24 hours. The required quantity of lime in powder form was added to soil and mixed thoroughly to ensure uniform mixing.

The soil specimens for the determination of unconfined compressive strength were prepared by compacting soil-lime mixtures at their respective optimum moisture contents and maximum dry densities. The samples were cured for 1, 3, 7 and 14 days in a desiccator at 100 percent relative humidity. The samples cured for 1 day were soaked for 1 hour and samples cured for 3, 7 and 14 days were soaked for 1 day. Samples were soaked by immersing them in a sand bath filled with water such that the samples were completely immersed. The soaked samples were kept in air for drying for about 30 minutes then subjected to unconfined compressive strength test. Three identical specimens were cast and tested in each case. The results are the average of the three tests.

IV. RESULTS AND DISCUSSIONS

Fig 1 shows the effect of addition of lime on Atterberg's limits. It is observed that both liquid limit and plastic limit for soil with 1 % lime increases slightly but there after decreases with further increase in lime content. The initial increase in liquid limit indicates flocculation of soil particles due to addition of lime. The effect of cation exchange of soil particles with calcium ion which decreases liquid limit due to suppression of diffuse double layer is negligible for Suddha soil with very low cat ion exchange capacity. The effect of flocculation which increases the water holding capacity within flocculated structure is maximum at 1 % lime and does seem to increase further with increase in lime content. The same is the case with plastic limit of soil. The continuous decrease in the plasticity index of soil with lime content shows that the increase in plastic limit is more than increase in liquid limit there by a net reduction in plasticity index.

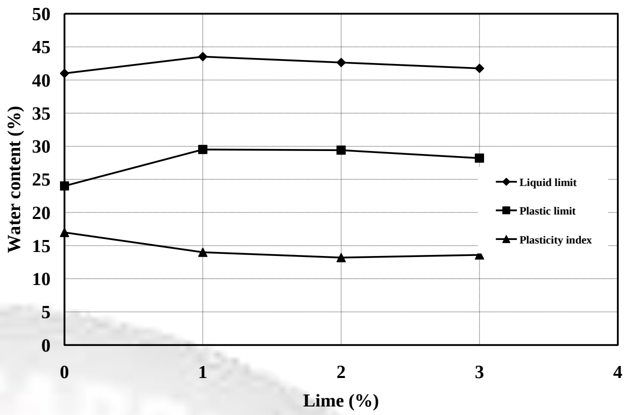

Fig. 1: Effect of Lime on Atterberg's limits

Fig 2 shows compaction curves for various soil lime mixtures. It can be observed from the graph that for all the three percentages of lime the value of optimum moisture content is less than the optimum moisture content of Suddha soil without the addition of lime. But the optimum moisture content has decreased when 1 % lime is added to soil, but there after for the addition of 2 % and 3 % lime optimum moisture content has increased. Thus the highest maximum dry unit weight and lowest optimum moisture content has been obtained for soil with 1 % lime. Actually flocculation of soil particles which has been indicated by Atterberg's limit should have decreased the maximum dry density and increased optimum moisture content. At one percentage of lime though the soil particles are flocculated there is no sufficient lime to bind the flocculated particles. Thus during compaction the flocculated particles might have collapsed leading to higher unit weight and lower moisture content. As the lime content increases the soil particles are slowly cemented increasing the particle resistance to compactive effort and reduction in the unit weight and increase in the water content.

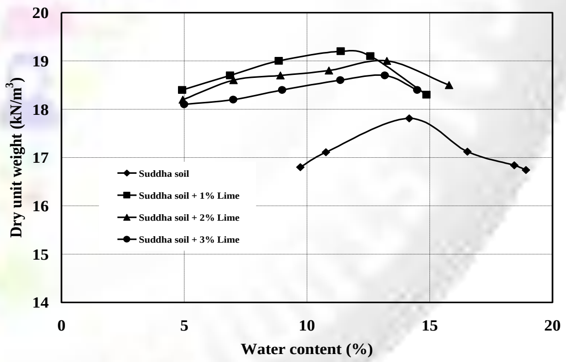

Fig 2: Compaction curve of Suddha soil with lime

Fig 3 shows unconfined compressive strength of soil with different lime percent under unsoaked condition. It is observed that there is an increase in unconfined compressive strength of soil with increase in lime content. It was observed that Suddha soil possesses good strength in dry condition and upon increase in moisture content looses strength. Hence lime is used as additive to improve the strength of soil under soaked condition. Fig 4 shows unconfined compressive strength of soil with different lime content under unsoaked condition and after curing for 1, 3, 7 and 14 days under soaked conditions. The strength of soil does not improve with 1 percent lime even after curing for 14 days because of the formation of flocculated structures as explained earlier. The strength of soil increases with higher percentages of lime both with lime content and curing period. It was earlier observed that the density of soil is highest with 1 percent lime. Thus the effect of pozzolanic reaction which proceeds well with higher percentage of lime masks the effect of density. With increase in lime content the rate of increase in strength increases with curing period. The effect of curing period is seen more clearly from fig 5 which presents the results of unconfined compressive strength with curing periods. At any given curing period, the strength gain is more with increase in lime content. In the present case minimum lime content shall be 2 percent with curing period not less than 3 days under soaked condition.

When excess lime is added, it acts as a filler material resulting in lowering strength. The optimum lime content depends on the clay content of the soil and the reactive silica. The soluble silica increases as the fineness of clay increases and the lime required to completely react with this silica increases. Water content is essential for pozzolanic reaction to produce gelatinous compounds. Effective formation of pozzolanic compounds does not take place when sufficient quantity of water is not available for soil lime reaction. On the other hand when water is more than required, the distance between soil particles increases which lead to lowering of strength because of ineffective binding by pozzolanic reaction compounds. Hence type of clay and water quantity present in the system influence the optimum lime content. Thus at optimum moisture content , optimum lime content required for effective stabilization of soil is found to be between 3 to 6 percent (Sivapullaiah et al 2000).

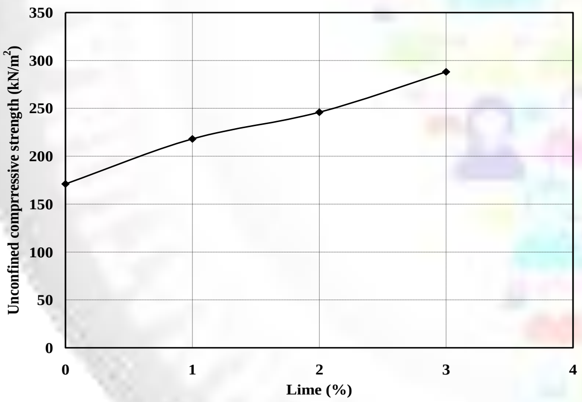

Fig. 3: Unconfined compressive strength of Suddha soil with Lime under unsoaked condition

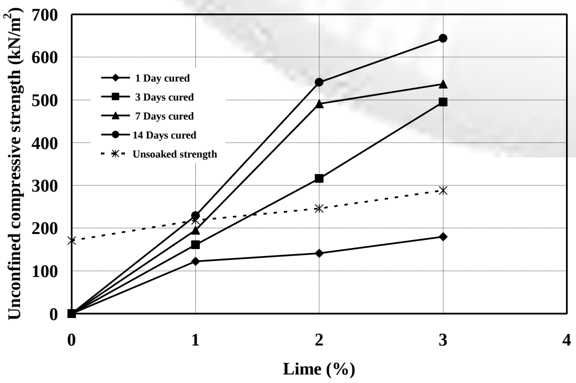

Fig. 4: Unconfined compressive strength of Suddha soil with Lime

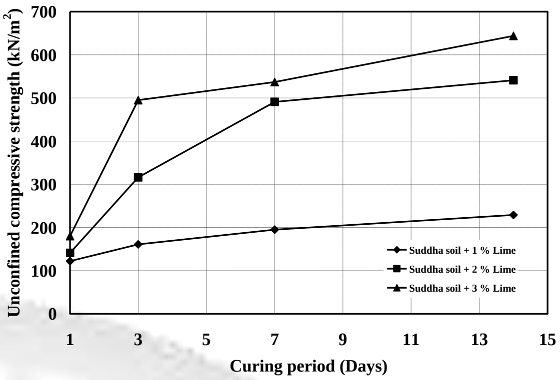

Fig. 5: Effect of curing period on Unconfined compressive strength with Lime

Fig 6 shows the stress-strain behavior of Suddha soil and lime stabilized Suddha soil under unsoaked condition. The unconfined compressive strength has increased with increase in lime contents. In order to determine the Young's modulus, the stress strain curve could be represented in hyperbolic form (Kondner 1963) as shown in the fig 7 and could be used to obtain strain dependent Young's modulus as shown in equation 5.

$$E_s = \frac{\Lambda\sigma_1}{\in} = \frac{1}{a + b\in} \qquad (5)$$

'a' is coefficient and 'b' is the slope as shown .

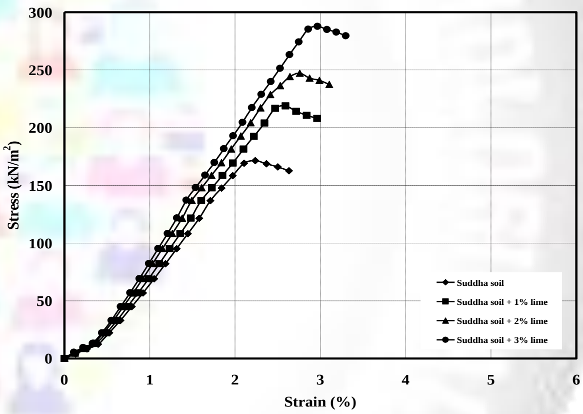

Fig 6: Axial stress- strain in unconfined compression strength test

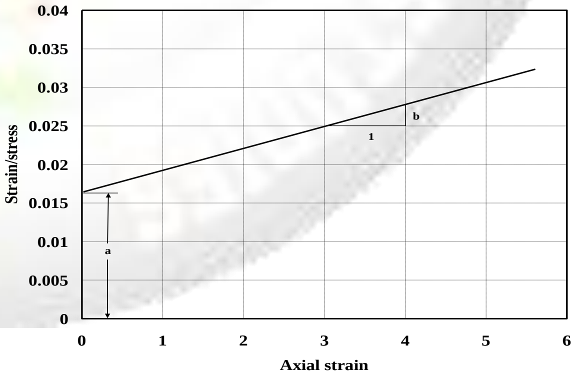

Fig 7: Tranaformed representation of stress strain

Fig 8 shows Young's modulus for lime treated Suddha soil. At any given percentage of lime content young's modulus is higher. There is a steep increase in the Young's modulus up to 2 percent of lime and thereafter there is a gradual increase with increase in lime content. Fig 9 shows Young's modulus for lime treated soil with curing period. The increase in Young's modulus is rapid up to 3 days and increases with decreasing rate after 3 days of curing period and it stabilizes at 14 day curing period.

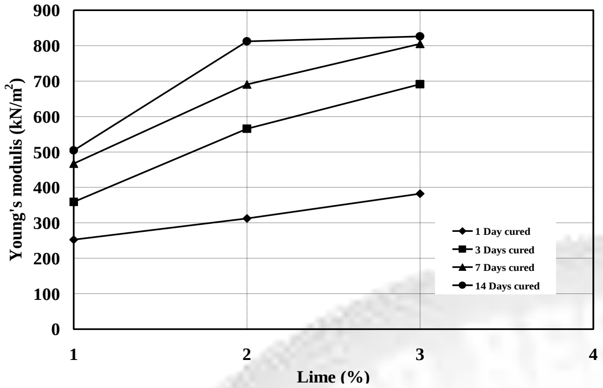

Fig 8: Young's modulus versus Lime content

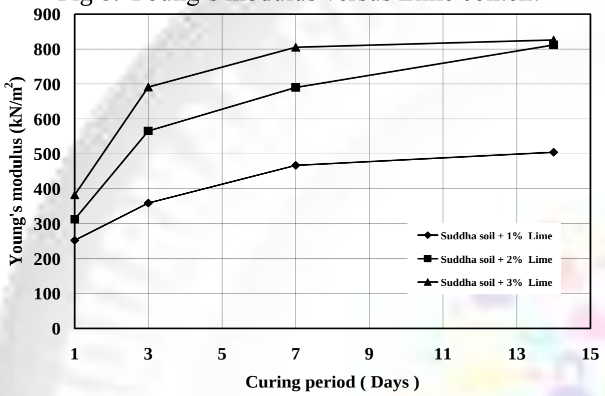

Fig 9: Effect of curing period on Young's modulus

It is thus clear that the Young's modulus of the soil is increasing with lime content and also with curing period. It was noted earlier that the unconfined compressive strength of the lime treated soil is also increasing similarly. Hence an attempt is made in this paper to study the relationship between the unconfined compressive strength and Young's modulus. Figure 10 shows variation of Young's modulus with unconfined compressive strength for lime treated soil. It is noted that there exists a good correlataion between young's modulus and unconfined compressive strength for lime treated and cured soil for a wide range of curing period. This shows that the soil is completed cemented.

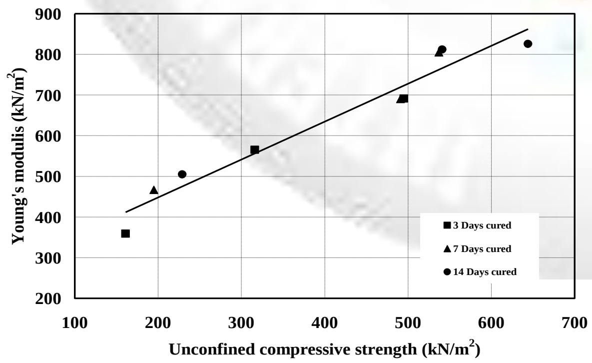

Fig 10: Young's modulus versus unconfined compressive strength for lime treated Suddha soil

V. Conclusions

Laboratory investigation for the behaviour of dispersive Suddha soil is carried out. Lime is found to be effective to improve the behaviour both under soaked and unsoaked conditions. The following conclusions are made

1) Unconfined compression strength test is more reliable than particle size distribution for measuring dispersion.
2) There is reduction in optimum moisture content and an increase dry unit weight with addition of lime. Flocculation is significant when lime content is low and cementation influences at higher lime content.
3) There is significance improvement in soaked strength when lime content is greater than 2 percent. The optimum lime content for reducing dispersion is 3 percent.
4) There is a good correlation between unconfined compressive strength and Young's modulus for stabilized soils

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