EXPERIMENTAL STUDY ON GROUND IMPROVEMENT OF SOFT CLAY BY USING SOIL-LIME COLUMN

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***Abstract*:** In this modern era, improvement of ground is necessary every now and there in projects. Various ground improvement techniques have been developed over the past few years. Increase in bearing capacity by placing more stiff material in ground was one of the techniques. In this study, soil-lime columns are used as binder material for ground improvement. Further these tests are compared with the only soil bed.

Model experiments are performed for soil with lime as a columnar inclusion. 4cm dia columns are used for performing experiments. Model tests are carried out after 7 days of placing in order to give lime to react with soil. Obtained results are compared with the results of the only soil bed. Model experiment is done for each case i.e., only soil bed, soil+3% lime column, soil+6% lime column and soil+9% lime column.

In this study, soil+6% lime column gave the more improvement followed by soil+3% lime column and soil+9% lime column. Hence at the end of the experiment we can say that Soil-lime columns can be used in ground improvement where there is more requirement of bearing capacity in an economical way as the lime is readily available at local markets at a cheap rate.

Keywords – Ground Improvement, Bearing Capacity, Columnar Inclusion, Soil-Lime Column, Model Tests.

1. Introduction

1.1 Background

India, where the modern generation is claiming a fast and imperative infrastructure development for the overall development of the nation, there is a need to expand the construction activities in a large scale. Hence, now a days the construction activities have been expanded to the zones with poor subsoil conditions also. The use of land in such weak strata challenges geotechnical engineers by the presence of various problematic soils with various different engineering characteristics. Pile foundations can be used in large scale projects but in case of small-scale projects where the soil can have some settlement an alternative technique is needed for improving the ground characteristics. The type of soil plays a major role behind the mechanics of ground improvement. A method for increasing the strength of the weak foundation soil is the inclusion of cylindrical columns which are made up of a material having higher strength characteristics.

Stone column serves as one of the best applications. Stone columns are successfully used to support the earthen embankments, LPG storage tanks, raft foundations, bridge approach fills, to increase stability of slopes and to reduce the liquefaction potential of loose cohesion less soil. But stone columns have got less stiffness and their strength depends upon the confinement provided by the surrounding soils. Hence, these columns are not suitable in soft soils, organic soils and peat. To overcome these limitations of granular column a new technique of using soil stabilizer as columns is introduced. Soil with lime and cement is vastly used currently for increasing strength of the pavement. Lime being cheaper and by product of various companies is used most.

The main aim of this thesis is to work with the same concepts of stone column but instead of granular backfill soil-lime columns are used. The installation and basic assumptions are the same as the stone column. A number of soil-lime columns are to be studied with various percentage of lime mixed with the soil.

The soil-lime column is having more stiffness as compared with the surrounding clay and ultimately it acts as reinforcement for the weak soil. Column supported embankment is one of the main areas of application of soil-lime columns and it is very useful when the construction time is short.

1.2 Fundamental Concept of Stabilization

When dry un-slacked or quick lime is mixed with the high to very high moisture content clay soils a combination of beneficial chemical and physical reactions and products occur. These include cat-ion exchange, ion crowding, flocculation, agglomeration and pozzolanic cementation. The extent of these reactions and products depend upon the quantity of quick lime added. One of the first reactions to occur in the clay water system is between quick lime and water.

$$CaO + H_2O = Ca\ (OH)_2 + Heat$$

The resulting hydrated lime, Ca $(OH)_2$ adds free calcium and hydroxyl anions to the clay water system. Cation exchange can then proceed with an abundance of calcium cat-ions in the elevated pH environment created from excess hydroxyl anions in the system.

Complex reactions of hydrous silica and alumina, dissolved from clay particles in a high pH environment, with calcium ions from gradually hardening cementitious material. As long as the pH remains above approximately 10, the reactions continue, but dissolution of silica and alumina is a hydroxyl consuming process. Adequate quick lime must be introduced into the system initially to allow for hydroxyl consumption (pH lowering) to occur over a long period of time in order for strength to continue to gain

Heat produced from the exothermic quick lime and water reaction also accelerate hydration reactions in-situ mixing allows adjacent under treated soil to provide constant sources of moisture and cool temperature which are ideal for curing conditions.

1.3 Soil-Lime Column

The technique of soil - lime column was considered as an alternative to rigid inclusion and stone column. Actually, the stone column was generally assumed to be too soft in terms of stiffness and bearing capacity and the rigid inclusions are too stiff, the soil-lime columns represents the intermediate case which provides better homogenous distribution of load on the sub-grade layer and provides almost uniform settlement profile. Soil with certain lime content is mixed and placed inside the columns. Deep mixing is also another type of placement of columns. This method mixes in situ soil with hardening agent by augers. It can be accomplished by wet or dry method. In wet method, binder is used in a slurry form, while dry method uses the binder in a powder form.

1.3 Lime

Lime: Lime can be used to treat soils to varying degrees, which depends on the objective of a particular project. The least amount is used to dry and treat soils, which provides a working technique, which produces permanent structural stabilization of soils. Most lime used for soil treatment is high calcium lime, which contains magnesium oxide or hydroxide. Lime can be applied in the form of quick lime (calcium oxide – CaO), hydrated lime (calcium hydroxide Ca $[OH]_2$) or lime slurry to treat the soil. Hydrate lime is created when quick lime reacts with water. This hydrated lime reacts with clay particle and transform them into a strong cementitious matrix.

2. Literature Review

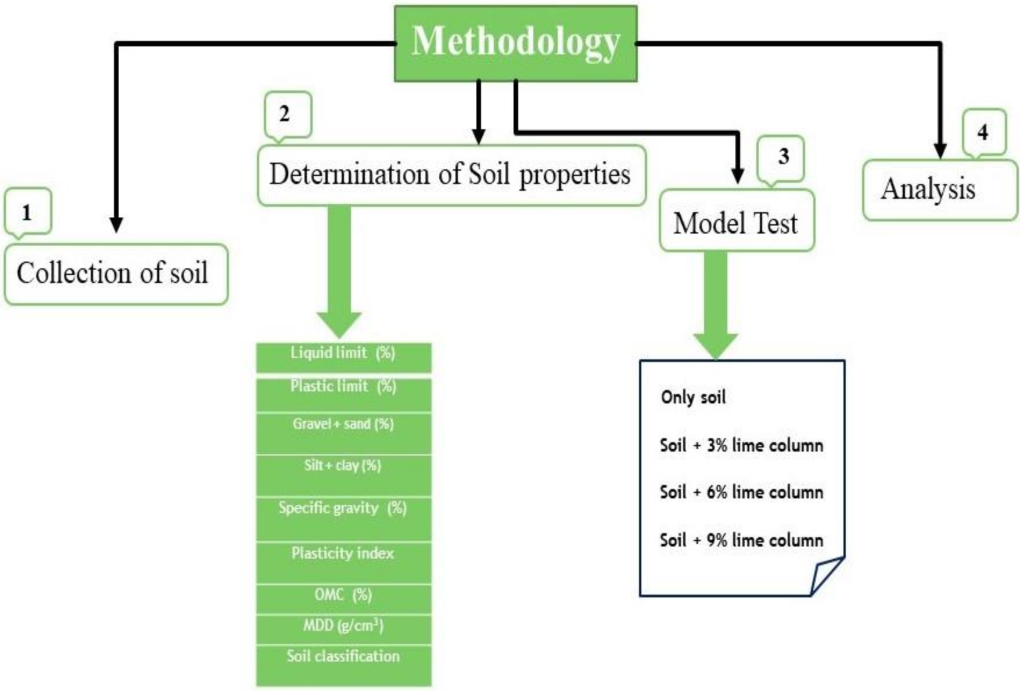
- **Kaur et al (2012)** discussed the stabilization of soil with lime by varying the lime content. Process of soil stabilization occurs when lime is added to a reactive soil to generate long-term strength gain through a pozzolanic reaction. That reaction produces stable calcium silicate hydrates and calcium aluminate hydrates as the calcium from the lime reacts with the aluminates and silicates solubilized from the clay. This pozzolanic reaction can continue for a very long period of time, even decades -- as long as enough lime is present and the pH remains high (above 10). As a result of this, lime treatment can produce high and long-lasting strength. Lime in the form of quicklime (calcium oxide-CaO), hydrated lime (calcium hydroxide-CalOH]2), or lime slurry can be used to treat the soils. Different tests are performed in this project are 1) Modified Procter Test, 2) Unconfined Compressive Test, 3) Plasticity Index (PI). Among the tests performed with lime content of 3%, 6%, 9%. Soil which consists of 6% lime gave the highest Unconfined Compressive Strength and OMC, MDD increased with increase in lime content.

- **Ambily and Gandhi (2007)** studied stone columns improved ground mainly due to higher stiffness of the columns compared to the soil, hence the most critical factor which controls the design of the stone column improved ground is the stiffness of the column and load between column and soil. This paper deals with developing a design procedure considering load sharing between columns and soil. The behaviour of interior stone columns among a group of large number of stone columns are analysed by varying parameters like spacing between the stone columns, shear strength of the clay, angle of internal friction of stone, etc sharing.

- **Malekpoor and Poorebrahim (2011)** conducted large scale laboratory model tests to investigate the behaviour of Compacted Lime-soil (CL-S) rigid stone columns in soft soils. The unit cell idealization is used for contruction of composite specimens to evaluate the influence of different paeameters such as the diameter of the column (D), the slenderness ratio (L/D) and the area ratio (Ar).

- **Melvin and Peter (2001)** had background for lime cement column process and some with other deep stabilization processes are presented. The specific use to support a vertical mechanically stabilized earth wall between Ì 0 and 12.5 m high is described. The wall was constructed without the need for "'staged" construction and has exhibited no significant comparisons shear deformations and only small settlements.

3. Methodology



3.1 Collection of Soil

The soil samples were collected from surroundings of Rajahmundry.

3.2 Determination of Soil Properties

The tests conducted for determining the properties of soil are-

- Sieve Analysis
- Liquid Limit Test
- Plastic Limit Test
- Specific Gravity Test
- Unconfined Compression Test
- Standard Proctor Test

Table: liquid limit test observation.

Determination No.	**1**	**2**	**3**
Weight of container (W_1)	24.5gm	24.5gm	24.5gm
Weight of container + wet soil (W_2)	59.5gm	52.5gm	67.5gm
Weight of container + oven dried soil (W_3)	50gm	45gm	54gm
$\mathbf{W=\frac{W2-W3}{W3-W1}}$	0.37	0.36	0.45
No. of blows	25	22	14

Table: plastic limit test observation.

Determination No.	1	2	3
Weight of container (W_1)	25gm	25gm	19.5gm
Weight of container + wet soil (W_2)	28gm	29gm	22gm
Weight of container + oven dried soil (W_3)	27.5gm	28.3gm	21.7gm
$W = \frac{W2-W3}{W3-W1}$	0.33	0.21	0.13

Table: Observation of Standard Proctor Test

Determination No.	1	2	3	4	5
Volume (cm^3)	2000	2000	2000	2000	2000
W_1 (Mould weight) (g)	5735	5735	5735	5735	5735
W_2 (Weight of mould + soil) (g)	9630	9740	9820	9795	9692
Compacted soil weight, W (g)	3895	4005	4085	4060	3975
Bulk-density, $\gamma_b = \frac{W}{V}$ (g/cm^3)	1.9475	2.0025	2.0425	2.03	1.9785
Water content (%)	14.28	15.29	16.98	18.96	20.95
Dry density, $\gamma_d = \frac{\gamma b}{1+w}$ (g/cm^3)	1.704	1.736	1.746	1.706	1.635

3.3 Model Test

The test planned for finding out the behaviour of soil-lime column are given in the Table below

Table: schedule of laboratory model test

Type of column test
Only soil
Soil + 3% lime column
Soil + 6% lime column
Soil + 9% lime column

4. Physical Modelling

Evaluating the behaviour of soil can be done through physical modelling methods. Since finite element is completely based on the values of the modulous of elasticity, Cohesion and Angle of internal friction, Elasticity value may change from place to place. A physical model is required for obtaining and checking the real behaviour of soil in site. For this physical modelling in small scale, steel moulds are used. Dimensions of the model are 14.5cm of diameter and 16.5cm of height. A steel tube sampler of 4cm diameter has been used for boring and making columns. Which by application of force, penetrates into the soil bed while removing comes out with, making a hole in the clay bed prepared.

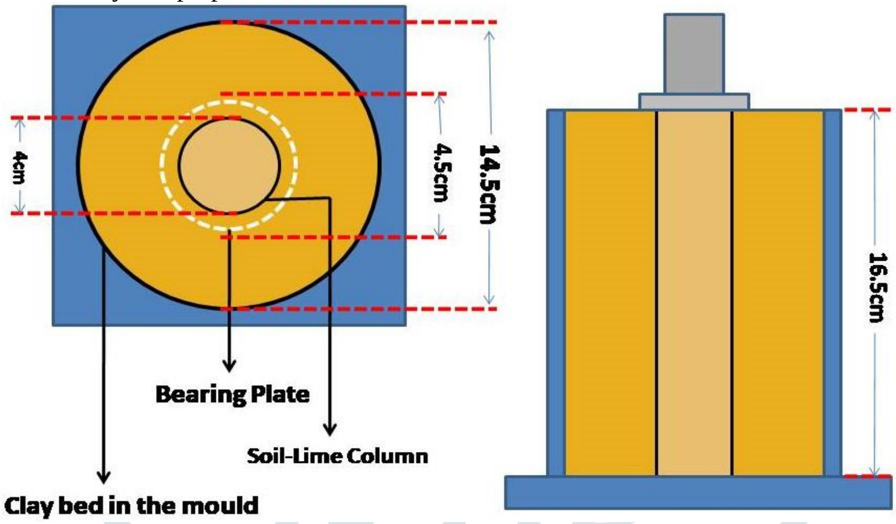


Fig: model soil-bed

5. Results and Discussions

5.1 Physical Modelling Results

A total 4 number of model tests were performed as discussed. This section shows its results. Preliminary tests were conducted on soil and its results are discussed below.

The properties of soil found out in laboratory are given below.

Table: properties of soil

Sieve analysis	Soil
Liquid limit (%)	37
Plastic limit (%)	22
Gravel+sand (%)	34.5
Silt+clay (%)	65.5
Specific gravity (%)	2.45
Plasticity index	15
OMC (%)	17
MDD (g/cm^3)	1.75
Soil classification	CI

5.2 Model Test Results

As mentioned in schedule, tests were performed and results are plotted in the figure below. From the results it is clearly seen that soil+6% lime column has got maximum stress value of 61.14KN/m^2, followed by soil+3% lime column has got stress value of 50.95KN/m^2, for soil+9% lime column it is 44.16KN/m^2. Results of only soil bed, which gave stress value of is 16.98KN/m^2 also included in order to compare the results. All the values are calculated at 40mm settlement. When compare to only soil bed all the soil-lime column improved bed gave more strength. Load vs settlement curve is drawn for the model tests in Figures below.

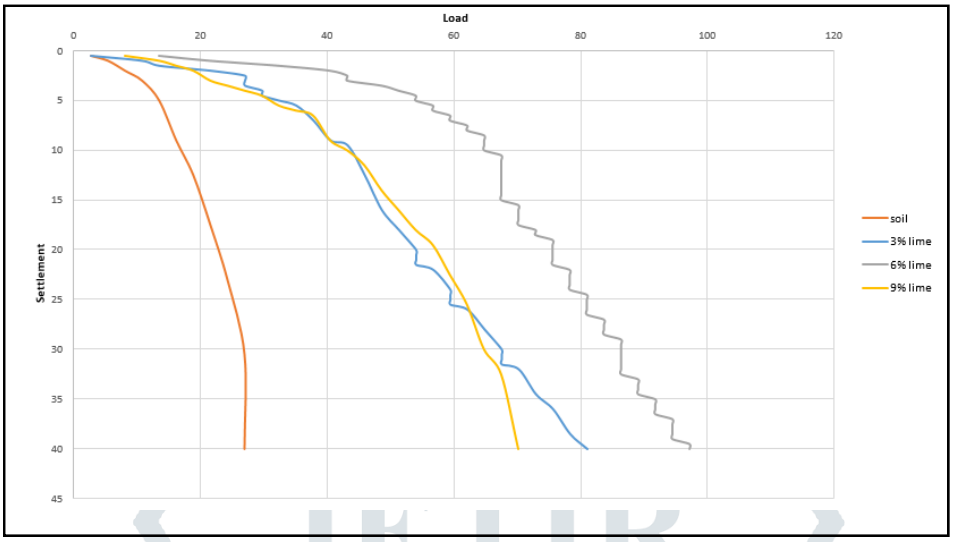


Fig: load vs settlement curve for soil-lime columns

Table: bearing capacity and percentage improvement for experimental study

Type of column	Bearing capacity at 40mm settlement	% improvement
Only soil bed	16.98KN/m^2	--
Soil+3% lime	50.95KN/m^2	**200%**
Soil+6% lime	61.14KN/m^2	**260%**
Soil+9% lime	44.16KN/m^2	**160%**

6. Conclusions

Following are the conclusions obtained from experimental studies, -

- From experimental results, Soil+6% lime column gives the maximum bearing capacity in all the cases, followed by Soil+3% lime column, Soil+ 9% lime column.
- From the experiment, the bearing capacity obtained from the only soil bed is 50.95KN/m^2 at 40mm settlement.
- For soil+3% lime column, the improvement of bearing capacity when compare to only soil bed is 200% at 40mm settlement.
- For soil+6% lime column, the bearing capacity improved by 260% when compare to only soil bed.
- The bearing capacity soil improved by 160% by the soil+9% lime column.
- Soil+9% lime column has got less improvement percentage as compared to other columns because atfer the certain percentage of increase in the lime, reactions between soil and lime start decreasing and one point comes when all reactions completes and value of unconfined compression stars decreasing.
- From the over all experimental results, we can say that the mixing of lime at centain amount is able to improve the strength properties of the soft clayey soil.

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