Effect of Lime Precipitation Technique on Strength Characteristics of Cohesive Soil

Pooja M. Vijay[1], Dr. Usha Thomas[2]

[1]M. Tech Geotechnical Engineering, St.Thomas Institute for Science and Technology, Kerala Technical University, Trivandrum Dist, Kerala, India

[2]Professor, St. Thomas Institute for Science and Technology, Kerala Technical University, Trivandrum Dist, Kerala, India

Abstract: ***Lime is being extensively used for the stabilization of clay soil in spite of the associated difficulties. Increase in strength and control of swell-shrink potentials suffer from certain difficulties and drawbacks in clay soil deposits by direct mixing of lime. The present study showed that sequential permeation of calcium chloride and sodium hydroxide solutions with clay soil resulted in the in situ precipitation of lime in the soil mass. Laboratory-scale model tests substantiated the efficiency of lime precipitation in stabilizing clay soil. Testing of soil were done as a model study and a strength profile was established which showed that strength increases with depth of soil mass. Settlement and swelling pressure of lime precipitated soil was found to be minimum at that depth where higher strength is observed.***

Keywords: Lime precipitation, Pozzolanic reaction, swelling pressure, ucc

1. Introduction

Lime is calcium containing inorganic mineral in which oxides and hydroxides predominate. In the strict sense of the term, lime is a calcium oxide or calcium hydroxide. Calcium hydroxide can be precipitated in the soil by using two chemicals namely calcium chloride and sodium hydroxide. Calcium chloride is an inorganic compound which is a colourless crystalline solid at room temperature and is highly soluble in water. Sodium hydroxide is also known as lye and caustic soda, is an inorganic compound with the formula NaOH. It is a white solid ionic compound consisting of sodium cations and hydroxide cations. Stabilization using lime is a widely adopted method from olden days. Lime has proved to be an useful additive in improving the strength as well as in modifying the properties of soil. The detrimental swell-shrink movements of expansive clay during wet and dry seasons can also be controlled using various lime treatment methods. Lime reacts with clayey soil in presence of water and alters the physico-chemical properties of clay. The physico-chemical changes are indicated by short term lime modification reactions and long term soil-lime pozzolanic reactions. Modification reaction by lime is rapid and occur primarily from cation exchange between calcium ions in the lime and metal ions on the surface of clay particles thereby clay particles flocculates. This cation exchange results in the marked reduction of diffuse double layer thickness around the clay particles, also increases the flocculation of clay particles, thus transforms soil into more friable and less plastic coarser material. Soils with high alkaline pH produced by lime facilitates the pozzolanic reactions. Usually this pozzolanic reactions occur relatively slowly. New cementitious compounds like calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) are formed due to the dissolution of silica and alumina in clay lattice, as these dissolved ions reacts with calcium available in lime. The newly formed compounds crystallizes with time leading to increased soil strength and durability.

The conventional methods gave a way for new methods for the improvement of ground. Insitu precipitation of lime is one such method by which successive permeation of calcium chloride and sodium hydroxide solutions into the clayey coil is done. Lime precipitation occurs as per the following equation,

$$CaCl_2 + NaOH \rightarrow Ca(OH)_2 + 2NaCl$$

The precipitated lime reacts with soil and modifies the properties of soil by both lime modification and pozzolanic reactions. Old researches had proved the effect of consecutive mixing calcium chloride and sodium hydroxide with expansive soil.

T. Thyagaraj and Samuel Zodinsanga (2014) conducted study on the “Swell-shrink behaviour of lime precipitation treated soil” by precipitating lime in expansive soil by the consecutive mixing of calcium chloride and sodium hydroxide into the soil mass. They examined the efficiency of lime precipitation technique in controlling the swell-shrink potentials and strength characteristics of expansive soil subjected to cyclic wetting and drying. Sequential mixing of both the chemicals resulted in significant reduction of liquid limit and plasticity index and significant increase in shrinkage limit. They have also done another study by permeating both calcium chloride and sodium hydroxide by making a central hole in the test mould. Results showed that strength properties and swell-shrink behaviour has been improved. **Rao and** Venkataswamy (2002) studied the “Effect of lime pile treatment on natural ground” by creating holes on ground filled with lime. The study showed that lime pile treatment reduced swelling potential and plasticity index, and slightly increased the strength. Lime pile treatment increased soil pH to 8.41-9.1 only, which is not a conducive condition for pozzolanic reactions to occur.

2. Materials Used

A. Clay soil

The soil was air-dried, pulverised and sieved by a 2 mm sieve before its compaction characteristics, swell potential, and strength characteristics were determined.

Physicochemical and index properties were determined on the soil fraction passing a 425-μm sieve. Properties are shown below.

Table 2.1: Properties of clay soil collected from field.

Property	Value
pH	6.06
Pore water salinity(mg/L)	582
Specific gravity	2.64
Liquid limit(%)	56
Plastic limit(%)	18
Grain size distribution	
Sand	0
Silt	29
Clay	71
Unified Soil Classification	CH
Maximum dry density(Mg/m3)	1.54
Optimum moisture content(%)	26
swell pressure(kg/cm^2)	51.26
Unconfined compressive strength(kN/m^2)	19.32

B. Calcium chloride

Calcium chloride is found as an odourless white powder, granules or flakes. It is an inorganic compound, a salt with the chemical formula $CaCl_2$. It has a density of 2.15 g/ml, melting point of 782° C and a high boiling point over 1600° C.

C. Sodium hydroxide

Sodium hydroxide is also known as caustic soda or lye with chemical formula NaOH and its molar mass is 40.01. It is an alkali salt of sodium. NaOH is an ionic compound consisting of sodium cation and hydroxide anion.

3. Methodology

a) Preparation of clay sample for finding index properties

The clay soil required for the study were first divided into 5 equal parts with each part containing 150 g of soil. This 150 g of clay soil with a natural moisture content of 23.9%, was mixed with 70 ml calcium chloride solution of desired concentrations, 10%,20%,35%,50% and 65% and each mix was allowed to equilibrate for 1 hour in a sealed air tight polythene bag. Subsequently, 70 ml of sodium hydroxide of desired concentrations, 7.3%, 14.6%, 25.5%, 36.4% and 47.3% was mixed with clay soil, and stored for equilibration for 24 hours. After the equilibration, index properties determined for evaluating the efficacy of lime precipitation technique.

b) Unconfined compression test sample preparation

A total of 97.95 g of expansive soil, with a natural moisture content of 23.9%, was mixed with 6.3 ml calcium chloride solution of desired concentrations, 10%,20%,35%,50% and 65% and then the mix was allowed to equilibrate for 1 hour in an air-tight polythene bag. After equilibration, 6.3 ml of sodium hydroxide solution of desired concentrations, 7.3%, 14.6%, 25.5%, 36.4% and 47.3% was mixed with clay and stored for equilibration for 24 hours and cured for a period of 7 days.

c) Procedure for in situ lime precipitation

The laboratory scale in situ lime precipitation experiments were conducted in a 600mm diameter cylindrical tank with 600 mm height. The clay soil was thoroughly mixed with optimum moisture content and filled inside the tank at field density. Clay soil inside the tank is then permeated sequentially with solutions of calcium chloride and sodium hydroxide at a concentration in which all the properties and strength is improved to its maximum. Both the solutions are permeated through a central hole which is bored in the compacted soil mass.

d) Permeation of cacl2 and NaOH

In order to facilitate the permeation of $CaCl_2$ and NaOH solutions into the soil in the tank, a central hole of 100 mm diameter was created in the soil mass to a depth of 300mm from the top. The volume of this hole corresponds to 1570.8 cm^3. This hole was loosely filled with coarse sand and through this central hole, 2000 mL of $CaCl_2$ solution was permeated into the soil mass in approximately 10 days. Subsequently, 2000 mL of NaOH solution was permeated into the soil mass in approximately 10 days to facilitate in situ lime precipitation. After the permeation of salt solutions into the soil mass, the soil mass in the test mould was covered with a wet cloth and then cured for a period of 28 days.

e) Sampling

After 28 days, sampling operation was performed at different depth and radial distance from the central hole for the determination of unconfined compressive strength and other properties. Representative samples was also be taken out as such for evaluating physicochemical and index properties. The physicochemical properties, index properties and unconfined compressive strength of in situ lime precipitation stabilized specimens was evaluated. Settlement of lime precipitated soil was determined and was found that settlement had a marked reduction when compared to untreated. Likewise swelling pressure also decreased.

4. Results and Discussions

a) Physico-chemical and index properties

Table 4.1: Comparison of physicochemical and index properties of treated specimens with untreated specimen

Specimen designation	pH	Liquid limit, %	Plastic limit, %	Plasticity index, %
Untreated	6.06	56	18	38
Specimen 1	9.51	51	20	31
Specimen 2	10.2	46	22	24
Specimen 3	10.6	42	23	19
Specimen 4	10.7	36	24	12
Specimen 5	11.2	30	25	5

The pH of treated specimens increased from 6.06 to 11.21. The strong alkaline pH values of treated specimens indicate that sequential permeation of calcium chloride and sodium hydroxide solutions into the clay soil mass resulted in the in situ precipitation of lime. The liquid limit of treated specimens decreased in the order of concentration of chemicals. i.e. the value of liquid limit decreases from the untreated soil sample to treated samples with 10%, 20%, 35%, 50% and 65% of $CaCl_2$ and 7.3%, 14.6%, 25.5%, 36.4% and 47.5% of NaOH solutions. The liquid limit of untreated soil is 56% and it has seen decreased to a value up to 30%.

b) Unconfined compressive strength

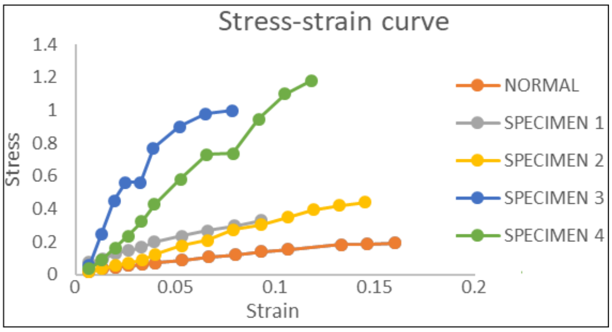

Figure 4.1: Compares the stress-strain plots of treated specimens with that of untreated specimens.

In the figure, stress-strain plot of untreated specimen corresponding to compacted condition (dry density = 1.54 g/cc and water content = 26%) is included as the reference. The unconfined compressive strength showed a marked increase. Here, strength increased with increasing concentration. Higher strength is observed at 65% calcium chloride and 47.5% sodium hydroxide. Soil was filled inside a cylindrical tank and chemicals were permeated at this concentration.

c) Liquid limit of soil mass cured in tank

The liquid limit of soil mass cured in the tank was found out at different depths and radial distance from the central hole. Improved index and engineering properties were observed as lime is produced in the soil itself by in situ precipitation of calcium chloride and sodium hydroxide.

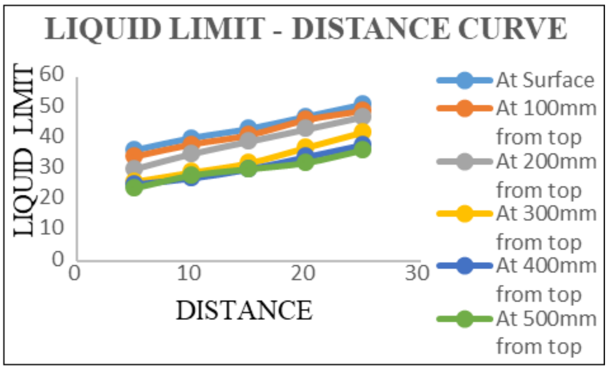

Figure 4.2: Liquid limit –distance curve corresponding to each depth

From figure 4.2. it is clear that liquid limit decreased with increase in depth. i.e. as depth increased from 5cm to 10 cm, liquid limit decreased, which shows a marked improvement of soil property. The diffusion of chemicals occurred at a faster rate at lower depths. Along with index properties chemical properties also changed due to the permeation of calcium chloride and sodium hydroxide solutions into the soil mass filled inside a cylindrical tank. pH of untreated soil was found to be 6.06 and it has seen increased to a value of 10.51 at the depth where improved properties were observed.

d) Unconfined compressive strength of soil mass cured in tank

Comparison of strength properties were also done at different depths and radial distance.

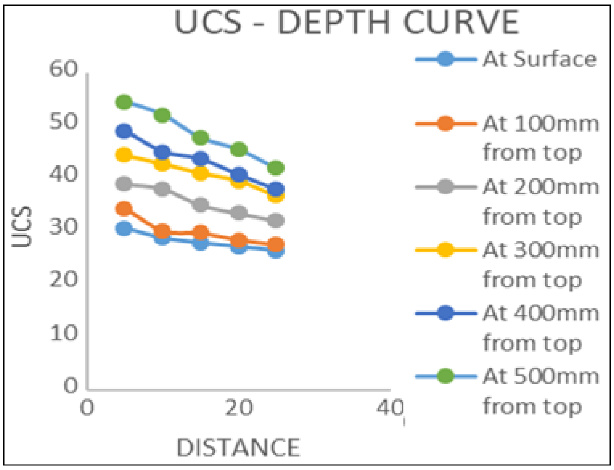

Figure 4.3: UCS-Depth curve corresponding to each depth.

Unconfined compressive strength of soil mass was found to be increased with lime precipitation technique. The treatment has found to be effective in improving strength of clayey soil. Also it has found to be increased with depth. The strength has found to be greater near the central hole through which permeation occurred. The short-term lime modification and long-term pozzolanic reactions were responsible for the improvement in strength. The dissolved alumina and silica in clay lattice get combined with calcium ions which leads to the formation of new cementitious compounds. Higher strength and brittle nature is due to these cementation bonds.

e) Load-Settlement

Settlement due to load and swelling pressure was found out at that depth where higher strength and improved properties were observed.

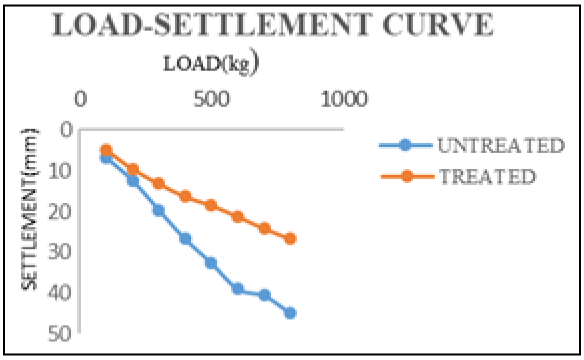

Figure 4.4: Comparison of Load-Settlement curve of treated and untreated soil.

From the figure, it is clear that settlement had a marked reduction due to lime precipitation. Swelling pressure of lime precipitated treated soil was found to be decreased to 14.26kg/cm^2.

5. Conclusions

- The sequential permeation of calcium chloride and sodium hydroxide solutions into the clay resulted in the precipitation of lime in soil mass and increased pH levels which are the conducive condition for pozzolanic reaction to occur.
- The well-developed cementation bonds from pozzolanic reactions substantially increased the unconfined compressive strength of lime precipitation treated specimens.
- Strength of soil mass increases with depth and was found to be greater near the central hole bored for the permeation of chemicals.
- Settlement of lime precipitated soil shows marked reduction when compared to untreated soil.
- Swelling of clay decreases due to lime precipitation.
- The present laboratory investigation clearly demonstrated the effectiveness of lime precipitation technique in stabilizing soil mass and showed that in situ precipitation of lime is better than sequential mixing of calcium chloride and sodium hydroxide.

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