Strength Behaviour of Clay Soil Stabilized With Lime

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Abstract. Geotechnical Engineers are searching for new sustainable material, which can be suitable and effectively used to improve the engineering properties of clay soil. In this research lime is used as stabilizing material in the variable percentage of 1\%, 3\%, 5\%, 7\%, 9\%, 10\%, 12\% and 15\%. Lime is used as the admixture for soil stabilisation. Swelling pressure of the soil mixed with various proportions of lime such as 1, 7, 12 and 15\%. Unconfined compression test, Plastic limit, Liquid limit, standard compaction proctor test, free swell index test and one-dimensional consolidation test are conducted to evaluate the clay soil strength in the laboratory. The experimental investigation results show that maximum strength improvement was achieved in the 12\% lime mixed with clay soil and the strength improvement in the range of 300kPa. The results of the swelling test showed that applying lime to the soil decreases the swelling nature of clay soils.

Keywords: Clay soil, Lime, Unconfined compression test, Free swell index test

1. Introduction

Clay soil undergoes swelling when water is getting added to them when they are dry. On drying, all clays shrink until the limit of shrinkage is reached. There are also special clays in which this problem is very pronounced, called expansive clays. The two main factors to consider in these swelling soils are firstly the amount of swelling and secondly the swelling pressure during swelling. It depends on the composition of the mineralogical and the amount of clay particles found in the soil. It is well recognized that because of the structural differences, montmorillonite absorbs more water than kaolinite. It is also
established that montmorillonite can be formed from limestone, while in the presence of magnesium ions and lack of leaching the black cotton soil of India has been formed from igneous rocks such as basalt in an alkaline environment. These soils exist in some parts of southern India, Bhopal and some other places [1-9].

Soil that exhibits a high volume change when it comes to water contact, called expansive soil. Black cotton soil is kind of expansive soil. This soil shows high plasticity, high free swell, high unconfined compression strength, high cohesion and lower penetration resistance against the CBR plunger. The liquidity property of the soil is high[10].

This soil forms cracks without prior warning. This cracks has average 7mm wide and 300mm deep. In south India structure of the black cotton, the soil is like a lentil seed. This type of structure is usually found near the Hyderabad. The subsurface shape of this soil is like a double-convex lens. At the start of the wet season, the infiltration rate is high in black cotton but the water content increases the infiltration rate drops in black cotton soil. Jewitt et al. investigated some African soils and found infiltration rates ranging from 0.2 mm / h ~ 0.5 mm / day, soil cracks are fixed and the profile becomes completely wet. The surface runoff occurs in such extremely low infiltration rate. In dry condition, Black cotton soil reveals high bulk density and low value in swollen stages. The bulk density of the soils may be (1~2) gm/cm3, depending on the dampness condition. (Jewitt et al.). American origin Black cotton soil having a bulk density range from (1.81~2.08) gm/cm3. Bulk density of Huston clay range from (1.59~2.1) gm/cm3. Black cotton soil in India (Hyderabad) expanded up to 60% when gets soaked from a dry state. The clay has a special property expect all the soils that do not have is known as plasticity. Water is electrical polar molecule, the polar molecule is a molecule in which centre of gravity of positive charges (Hydrogen) and centre of gravity of negative charge (Oxygen) which does not coincide. This causes water to the charged compound and made them react with the clay minerals. This cause the occurrence of an electrical double layer in the clay, this is the reason for the clay shows the special property named plasticity. Montmorillonite is the major component for the black cotton soil to show the high swelling (increase in volume) and shrinking (decrease in volume). Cracking occurs in the soil due to the shrinking of the soil. Shrinking is more dangerous than swelling in the structural point of view. Swelling cause the major problems in the lighter structures but shrinkage cause all types of structures [1-5].

Black cotton soil pH is generally varied from the 7.5 to 8.5. The pH of the black cotton soil indicated that the soil is alkaline. The alkalinity of the soil is because of the presence of the Calcium, Caco3 and magnesium salts in the soil. In Tropical countries like India, more fertilizers are used in the field, this will result in an increase of the sodium salts content in the soil. This will destroy the montmorillonite structure in the soil and pH will be increased to 9.5.

2. Materials and Methods

2.1 Soil Sample
Soil samples are obtained in the Coimbatore region at a depth of 0.5 m from the farm field. Excavation depth indicates that the chemicals and fertilizers do not affect at that depth. Soil is collected and dried out for experimental purposes. The basic soil properties were calculated using Indian Standard soil testing procedures and the results of the tests were tabled in Table 1. On sieve analysis over 50% of soil passes on the 75-micron sieve it shows that soil is either silt or clay. The plasticity index of the black cotton soil is 37. As per the A-Line graph, Plasticity is obtained as 36.5. Actual Plasticity Index is greater than A-Line Plasticity index so it confirms soil is clayey soil. Actual Liquid limit of the clayey soil is 70 % so that the soil is high compressible clay soil and it is indicated as CH. Free swell index of the soil is about 65 % so it confirms that the soil is expansive soil [11-14].
Table 1. The basic properties of soil sample

| S.No | Property                              | Test Results |
|------|---------------------------------------|--------------|
| 1    | Specific gravity                      | 2.69         |
| 2    | Particle size less than 0.075 mm       | 70%          |
| 3    | Liquid Limit                          | 60%          |
| 4    | Plastic Limit                         | 31%          |
| 5    | Plasticity Index                      | 35%          |
| 6    | Soil Classification                    | CH           |
| 7    | Maximum Dry Density                   | 1.32 g/cc    |
| 8    | Optimum Moisture Content              | 15%          |
| 9    | Unconfined Compression Strength       | 35.46 kN/m²  |
| 10   | Free Swell Index                      | 63%          |

2.2 Lime
Lime is an inorganic mineral containing calcium consisting mainly of oxides, and hydroxide, typically calcium oxide and calcium hydroxide. Such materials are also used as construction and engineering materials in large quantities (including cement, concrete, limestone products and mortar). Lime is commercially available in the market and in this study, the lime was purchased from VR chemicals, Erode. Lime properties were presented in Table 2.

Table 2. The basic properties of lime

| S.No | Property           | Results |
|------|--------------------|---------|
| 1    | Specific gravity   | 2.4     |
| 2    | CaO                | 72.11   |
| 3    | Al₂O₃ + SiO₂       | 25.75   |
| 4    | MgO                | 3.19    |
| 5    | Loss of Ignition   | 2.45    |
| 6    | Bulk density       | 2.0 g/cc|

3. Sample Preparation
3.1 Unconfined Compressive Strength
The UCC is a special triaxial test type in which the containing pressure is zero. Only clayey soil that is able to stand without any containment can be tested.

The sample shall be prepared for the test before the test is to be conducted. First SPCT is done and optimum soil moisture content is determined. The new soil sample is taken and combined with the
soil’s OMC and compacted as per SPCT. Then the SPCT mould is kept in the sample extractor in which the sample of the soil to be extracted for the UCC test. It is noted that the height of the sample used for the UCC at least equal to twice the diameter of that sample.

The sample is to be placed in the fixed bottom plate in the UCC apparatus. Proving is used to measure the compressive force applied in the specimen. The specimen has two plates that have one seated. The specimens are placed on the base plate to be in contact with the upper plate. The dial indicator and proving ring are set at zero. As the motor starts to rotate, the rotating upper plate applies compressive force. The strain is measured in dial gauge and the upper plate rotates in such a manner that the strain in the specimen does not exceed 2 percent per minute. The shearing continues until the specimen fails or until 20% of the axial strain occurs, whichever is earlier.

In UCC, soil cohesion is equivalent to half of an unconfined strength of the compression. The failure plane in the soil makes the 45 degree to the horizontal this is because a flexible material applied pure compressive load it fails at 45 degree. If the failure plane is drawn for the Mohr circle it shows semicircle and the minor principal plane stress is zero. In Mohr circle, the failure plane angle is 90 degree. It is again proof of that Mohr circle failure plane angle is half that in the material.

Stress-Strain graph is drawn for the Mohr circle. Stain in X-axis and Stress in Y-axis. The materials Unconfined compressive strength has been taken from the stress-strain graph of the UCC.

3.2 Consolidation Test
Consolidation test is used to evaluate soil consolidation rate and magnitude when the soil is laterally constrained and axially loaded. Often referred to as One-Dimensional Compression Test or Standard Oedometer is the consolidation test. This test is done on specimens of saturated soil, particularly in cohesive soils. Saturate two porous blocks, submerging them into distilled water for about 4 - 8 hours. Wipeout excess space. The consolidometer fittings to be mounted shall be moistened.

Arrange the consolidometer on top and bottom of the instrument with the soil specimen and porous stones, providing a filter paper between the soil and the porous stone test. Locate a pressure pad on a porous stone centred on top. Place the mould onto the load frame and position it so that the applied load is axial. Insert the dial gauge for vertical compression test of the specimen. The dial gauge holder should be calibrated to allow the dial gauge to run in the begging of its releases, leaving ample room, if any, for soil swelling.

Attach the mould assembly to the water reservoir, and allow saturation of the sample. The level of water in the reservoir will be approximately equal to that of the soil specimen. Initial load was applied to the assembly. This load should be magnitude not less than 50g/cm3. The loading must be allowed to stand until the dial gauge readings adjust for two consecutive hours or a maximum of 24 hours.

Notice the reading of the final dial under the p load. Apply 1st intensity load 0.1kg/cm2 and start the stopwatch simultaneously. Record the results of dial gages at different intervals of time. The readings of the dial gauge are taken before consolidation hits 90 per cent. The primary consolidation is achieved gradually in 24 hours.

This test can also be used to find the swell pressure of the expansive soil. Swell pressure is the pressure by which expansive soil attains the original volume. Swell pressure is found by plotting a graph between swell pressure (X-axis) and the change in volume (Y-axis). The test is repeated for a various percentage of lime.
4. Results and Discussion

Fig. 1 and Fig. 2 show that the effect of lime content on clay soil with one day and three days curing. The maximum strength of the soil is achieved in one-day curing was 327 kPa and for three days curing maximum strength was 367 kPa. The strength improvement was in the range of 10 times greater than the untreated soil for one day curing and for three days curing the strength improvement was 11.35 times the untreated soil. The UCC strength of the clay soil improved with increasing the lime content. But at a certain percentage of lime (e.g. 15%) the UCC strength decreases. Additional application of lime also reduces soil strength. The test results show that greater strength has been achieved at 12% lime for both one and three days curing period. The lime content added to the wet soil increases the pH of the soil which is responsible for strength improvement. The pH of lime mixed soil having pH in the range of 11 to 12. The test results showed that as the lime content applied to the soil raising the liquid and plastic limit to 12% of the lime and above that 12% of the lime applied, all limits started to decrease. The increase in Atterberg ‘s limits can be attributed to soil flocculation after lime content is applied. In this process, the clay particles appear to agglomerate and form huge aggregates. However, increasing the lime level by more than 12% results in a reduction of the liquid limit with an increase in plasticity for the samples being treated. The reason for such behaviour can be discussed via cation exchange capacity,
where calcium ions are released from the addition of lime which tends to replace other cations around the surface of the clay particle resulting in a reduction of double-layer thickness.

Kulanthaivel et al. (2020) demonstrated that the maximum strength of intermediate compressible clay soil stabilized with nano-silica was 294.461 kPa. In the current study, the maximum unconfined compressive strength of high compressible clay soil treated with lime content was 367 kPa. When comparing the above two studies indifferent results were identified because of the type of admixture, type of soil, treating method used in two studies were different[15].

![Consolidation test for untreated soil](image1)

**FIGURE 3.** Consolidation test for untreated soil

![Consolidation curves for 1%, 7% and 12% lime](image2)

**FIGURE 4.** Consolidation curves for 1%, 7% and 12% lime

One dimensional consolidation test can be used to find out the pressure at which swelling is arrested. The test is conducted for both untreated and treated samples of (1%, 7%, and 12% lime). The increased volume of untreated soil was in the range of 1.6. Adding lime content 1%, 7% and 12% decreases the volume of the soil 1.4, 1.0 and 0.4 respectively. The test results show that pressure required to arrest the swelling for the untreated sample is high when compared with the treated samples.

From the Fig.3 and Fig.4, the test data demonstrated that increasing the dosage of lime content reduces the consolidation pressure. At 1% lime content the pressure was 0.3 kg/m² and for 7% lime content the
consolidation pressure was 0.2. The lime content increased from 7% to 12% the consolidation pressure was reduced from 0.2 to 0.1 kg/m². Similarly, the volume was reduced from 1.6 to 0.4 when the lime content increased from 1% to 12%.

5. Conclusion

The clay soil stabilized with lime content gives the following conclusions.

(i) The maximum UCC strength was achieved by optimum lime content of 12%. Beyond this percentage addition of the lime, content decreases the strength behaviour of soils.
(ii) The maximum UCC strength was achieved as 327 kPa for one-day curing and 367 kPa for three days curing.
(iii) The swelling of soil was reduced at 12% lime content and the final volume was reduced in 1.6 to 0.4.
(iv) Addition of lime content to the clay soil increases soil strength characteristics and reduces swelling.

References

[1] Rama Vara Prasad, C., et al., Swelling characteristics of soils subjected to acid contamination. Soils and Foundations, 2018. 58(1): p. 110-121.
[2] Emarah, D.A. and S.A. Seleem, Swelling soils treatment using lime and sea water for roads construction. Alexandria engineering journal, 2018. 57(4): p. 2357-2365.
[3] Stoltz, G., O. Cuisinier, and F. Masrouri, Multi-scale analysis of the swelling and shrinkage of a lime-treated expansive clayey soil. Applied Clay Science, 2012. 61: p. 44-51.
[4] Onyelowe, K., et al., Scheffe optimization of swelling, California bearing ratio, compressive strength, and durability potentials of quarry dust stabilized soft clay soil. Materials Science for Energy Technologies, 2019. 2(1): p. 67-77.
[5] Latifi, N., et al., Micro-structural analysis of strength development in low-and high swelling clays stabilized with magnesium chloride solution—A green soil stabilizer. Applied Clay Science, 2015. 118: p. 195-206.
[6] Jamsawang, P., et al., Laboratory investigations on the swelling behavior of composite expansive clays stabilized with shallow and deep clay-cement mixing methods. Applied Clay Science, 2017. 148: p. 83-94.
[7] Thakur, V.K. and D.N. Singh, Rapid determination of swelling pressure of clay minerals. Journal of Testing and Evaluation, 2005. 33(4): p. 239-245.
[8] Chen, Y.-G., et al., Combined thermal and saline effects on the swelling pressure of densely compacted GMZ bentonite. Applied Clay Science, 2018. 166: p. 318-326.
[9] Guney, Y., et al., Impact of cyclic wetting–drying on swelling behavior of lime-stabilized soil. Building and environment, 2007. 42(2): p. 681-688.
[10] Langroudi, A.A. and S.S. Yasrobi, A micro-mechanical approach to swelling behavior of unsaturated expansive clays under controlled drainage conditions. Applied Clay Science, 2009. 45(1-2): p. 8-19.
[11] 4, I.-P., Indian Standard Methods of Test for Soils: Grain Size Analysis. 1985, Bureau of Indian Standards New Delhi. p. 73-91.
[12] IS, Methods of test for soils: Determination of liquid and plastic limit. 1985, Bureau of Indian Standards New Delhi.
[13] BIS, IS 2720 (Part 40)-1977: Determination of free swell index of soils. 1977, Bureau of Indian Standards New Delhi, India.
[14] IS and I.-P. 3, Methods of test for soils—determination of specific gravity. 1980, Bureau of Indian Standards New Delhi, India.
[15] Kulanthaivel, P., et al., Experimental investigation on stabilization of clay soil using nano-materials and white cement. Materials Today: Proceedings, 2020.