EFFECT OF LIME ON SOIL PROPERTIES: A REVIEW

Nivetha Babu[1], Emy Poulose[2]

[1]PG Student, Civil Department, Toc H Institute of Science and Technology, Kerala, India
[2]Asst. Professor, Civil Department, Toc H Institute of Science and Technology. Kerala, India

---***---

Abstract - *Soil stabilization can be defined as the modification of the soil properties by chemical or physical means in order to enhance the geotechnical properties of the soil. The principle objectives of the soil stabilization are to increase the bearing capacity of the soil, its protection from weathering process and soil permeability. The performance of any construction project depends upon the soundness of the underlying soils. But there are certain soils, like, expansive and unstable soils that create significant problems for pavements or structures. Therefore soil stabilization techniques are necessary to ensure the good stability of soil so that it can effectively support the load of the superstructure especially in case of soil which are highly active. This also helps to saves a lot of time and millions of money when compared to the method of cutting out and replacing the unstable soil. This paper deals with a review on the complete analysis of the improvement of soil properties and its stabilization using lime.*

Key Words: Lime Stabilisaton, Direct Mixing, Ion Migration, Precipitation, etc

1. INTRODUCTION

A developing country like India which has a large geographical area and population, demands vast infrastructure i.e. network of roads and buildings. Everywhere land is being utilized for various structures from ordinary house to sky scrapers, bridges to airports and from rural roads to expressways. Almost all the civil engineering structures are located on various soil strata. Every Civil Engineering structure is to be found on the soil. The soil on which the structure is to be built should be capable of withstanding the load to be imposed on it. However, naturally there exist problematic soils to be used as foundation or construction materials, such as expansive soils, whose engineering characteristics are mainly affected by the fluctuation of moisture content.

Soil stabilization is the process which involves in enhancing the physical properties of the soil in order to improve its strength, durability by mixing it with additives. Soil stabilisation can also be defined as the controlled modification of soil texture, structure and physical as well as mechanical properties. The methods of stabilisation can be broadly classified as physical, mechanical or binding. Physical stabilisation is the modification of soil particle size distribution and plasticity by the addition/subtraction of different soil fractions in order to modify its physical properties. Mechanical stabilisation is the modification of porosity of soil and inter-particle friction/ interlock by compaction or other means.

In line with this, the selection criteria for these stabilisation techniques should be the plasticity index and the relative amount of cohesive material as the key parameters. However, there are several other options in addition to lime and cement, for soil stabilisation including fibre reinforcement and polymers. Other stabilisers include chemical admixtures that offer specific functional properties such as set acceleration/retardation of hydraulic binders, plasticisers and hydrophobic admixtures.

1.1 Soil stabilization methods

Mechanical stabilization involves the use of physical processes. In contrast to chemical stabilization, it changes just the physical properties of soil through compaction, soil mixing i.e adding fibrous and non-biodegradable reinforcement or placing a barrier on the soil. In geotechnical engineering, soil compaction is a process wherein pressure is applied to soils by means of heavy machinery. It displaces air from the pores and causes soil densification. It is important to regulate the amount of pressure when compacting as excess pressure disintegrates soil aggregates and causes them to lose their geotechnical properties. Soil reinforcement is another method used in the mechanical stabilization of soils. In this technique, soils are strengthened by including geomaterials and plastic mesh to arrest soil disintegration and soil permeability. Other than this, graded aggregates can be added to soils to reduce soil plasticity.

Chemical stabilization alters the chemical properties of the soil through the use of admixtures. However, there are mechanical additives that are not able to alter the chemical properties of the soil, but they are able to reinforce the natural properties of the parent soil. This technique is more cost effective. Chemical processes such as mixing with cement, fly ash, lime, lime byproducts and blends of any one of these materials can be used to alter soil properties such as strength, compressibility, hydraulic conductivity, swelling potential and volume change properties. The additives are combined with the help of machines. The method used depends on the location and availability of the machine. There are many types of additives used for chemical stabilization. But the selection of additive is based on the type of soil. A single additive acts differently with different type of soils.

Bio-mediated method of soil improvement generally refers to the biochemical reaction that takes place within a soil mass to produce calcite precipitate to modify some geotechnical properties of the soil. The utilizisation of the interdisciplinary knowledge of civil engineering, microbiology and chemistry to change the soil engineering properties has emerged recently. The technique utilizes soil microbial processes, which is technically referred to as microbially induced calcite precipitation (MICP), to precipitate calcium carbonate into the soil matrix. The calcium carbonate produced holds the soil particles together thereby cementing and clogging the soils, and hence improves the strength and reduces the hydraulic conductivity of the soils. MICP can be a practicable alternative for improving soil-supporting both new and existing structures and has been used in many civil engineering applications such as liquefiable sand deposits, slope stabilization, and subgrade reinforcement.

It was revealed that microorganisms influence the formation of fine-grained soils and change the behavior of coarse-grained soils such as strength and hydraulic conductivity. They also facilitate chemical reactions within a soil mass, promote weathering and change the chemical and mechanical properties of specimens after sampling. Hence, the effects of these microorganisms on mechanical properties of soils are still not fully discovered in geotechnical engineering field. Though it was understood that there are more microorganisms in the subsurface than on the ground, and studies of many years have proved the relevance of biological activities in influencing soil behavior, less work has been done in exploring the importance, relevance, usefulness and application of biology in geotechnical engineering.

2. LIME STABILISATION

Lime provides an economical way of soil stabilization. The method of soil improvement where lime is added to the soil to improve its engineering properties is known as lime stabilization. The types of lime used to the soil are hydrated high calcium lime, monohydrated dolomite lime, calcite quick lime, dolomite lime. The quantity of lime is used for stabilisation is in the range of 5% to 10%. Lime modification results in an increase in strength by cation exchange capacity other than cementing effect due to the pozzolanic reaction. In soil modification, as clay particles flocculates, transforms natural plate like clays particles into needle like interlocking metalline structures. Lime stabilization can also be refered to pozzolanic reaction in which pozzolana materials reacts with lime in presence of water to form cementitious compounds. The effect can be brought either by quicklime, CaO or hydrated lime, $Ca(OH)_2$. Lime slurry also can be used in drysoils where water may be required to achieve effective compaction. Quicklime is the most commonly used lime.

2.1 Mechanism of lime stabilisation

Drying: If quicklime is used, it chemically combines with water and releases heat. Soils become dried, because water present in the soil takes place in this reaction, and the heat generated can evaporate additional moisture. The hydrated lime produced by these reactions will subsequently react with clay particles. These subsequent reactions will slowly result in additional drying because they reduce the soil's moisture holding capacity. If hydrated lime or hydrated lime slurry is used instead of quicklime, drying occurs only through the chemical changes in the soil that reduce its capacity to hold water and increases the stability of soil.

Modification: After initial mixing, the calcium ions (Ca++) from hydrated lime adsorb to the surface of the clay particles and displace water and other ions. The soil becomes friable and granular. At this stage the tendency of soil to swell and shrink reduces as well as the Plasticity Index of the soil decreases dramatically. The process, which is called "flocculation and agglomeration," generally occurs within a few hours.

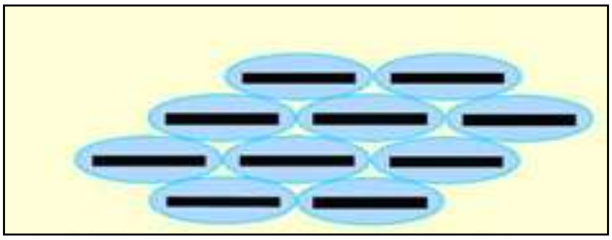

Fig-1: Flocculation of clay particles

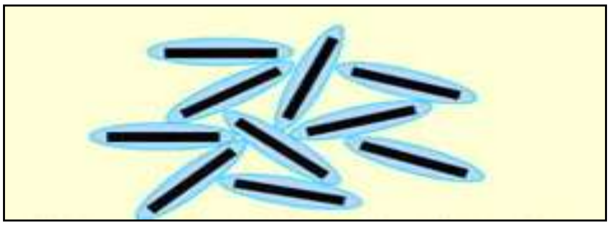

Fig-2: Dispersion of clay particles

Stabilization: When appropriate quantities of lime and water are added, and when the pH of the soil quickly increases to above 10.5, Silica and alumina are released and react with calcium from the lime to form calcium-silicate-hydrates (CSH) and calcium-aluminate-hydrates (CAH).

$$Ca\,(OH)_2 + SiO_2 \rightarrow CaO\text{-}SiO_2\text{-}\ H_2O$$
$$Ca\,(OH)_2 + Al_2O3 \rightarrow CaO\text{-}\ Al_2O3\text{-}\ H_2O$$

CSA and CAH are cementitious products similar to those formed in Portland cement. They form the matrix that results into the strength of lime-stabilized soil layers. As this matrix forms, the soil is altered from a sandy, granular material to a hard, relatively impermeable layer with significant load bearing capacity. The process begins within hours and can continue for years. The matrix formed is permanent, durable, and significantly impermeable, producing a structural layer that is both strong and flexible.

Fig-3: Effect of liming on consistency of soil

3. LIME STABILISATION TECHNIQUES

Stabilization using lime is an established practice to improve the characteristics of fine grained soils. The first field applications in the construction of highways and airfields pavements were reported in 1950- 60. With the proven success of these attempts, the technique was extended as for large scale soil treatment using lime for stabilization of subgrades as well as improvement of bearing capacity of foundations in the form of lime columns.

3.1 Lime Stabilisation by Direct Mixing

Bell (1996) investigated that clay soil can be stabilized by addition of small percentage by weight of lime thereby improving many of the geotechnical properties of the soil and producing an improved construction material. Three of the most frequently occurring minerals in clay deposits, namely kaolinite, montmorillonite and quartz were used in this study. The results show that the plasticity of montmorillonite was reduced while that of kaolinite and quartz increased. All the three minerals experienced an increase in their optimum moisture content and a decrease in their maximum dry density. A notable increase in the strength and young's modulus also occurred. The strength was also influenced by the curing period and the temperature.

Yildis and Soganci (2012) conducted a study on the effect of freezing and thawing on the strength and permeability of two clayey soils (high and low plasticity), which was stabilized with lime. The permeability and strength of the specimens were determined both before and after stabilization by varying the freeze-thaw cycles. Results shows that addition of 6% of lime increased the hydraulic conductivity of the specimens 1000 times after only 3 freeze-thaw for both clays. The strength of high plastic clay increased about 15 times at the end of 28 day curing, whereas the strength of stabilized low plasticity clay increased about 3 times only.

Umesha *et al.* (2013) has studied the effect of lime to improve the unconfined compressive strength of acid contaminated soil. Addition of lime of about 3 percent generally increases the unconfined compression strength of the soil but found to be ineffective to enhance the strength of contaminated soil. Addition of 3 percent lime has developed considerable strength after curing. The improvement in Young's modulus of stabilized soils is better for lime treated soil than contaminated soil.

Garzon *et al.* (2016) investigated the stabilization and improvement in engineering properties of a Spanish phyllite clay achieved by the addition of 3, 5 and 7 wt.% lime. Consistency limits, compaction, California Bearing Ratio, swelling potential and water-permeability are the geotechnical properties investigated. The addition of 3 wt.% lime was sufficient to get the desired results. Also, the lime percentage significantly reduced the plasticity index value, without any swelling under soakage.

Amidi and Okeiyi (2017) conducted a laboratory study to evaluate and compare the stabilization effectiveness of different percentages (0, 2.5, 5, 7.5, 10%) of quick and hydrated lime when applied separately to locally available lateritic soil. It was found that the quicklime reduced the plasticity while hydrated lime resulted in higher dry unit weight. Also, when soil sample was treated with quicklime, it resulted into higher UCS especially at higher dosages (7.5 and 10%). From the aforesaid results, quicklime is considered to have shown superior engineering properties and therefore creates a more effective stabilization alternative for the soil.

Soheil *et al.* (2017) investigated the effects of curing on geotechnical properties of stabilised kaolinitic clay with lime and geogrids. Geogrid was added to the lime-stabilised-clay in four layers at constant intervals and the engineering properties were also observed after the curing times. Based on the results the geotechnical properties of clay were improved significantly by adding lime and geogrid, however, by increasing the percentages of lime, the brittleness index increased and the deformability index decreased.

Innocent and Okonta (2018) studied the synergic effects of pre-compression and fiber inclusions, on the mechanical behaviour of lime fly ash stabilised soil. Randomly distributed 25 mm sisal fibers were mixed with stabilised soil at the contents of 0%, 0.25%, 0.5%, 0.75% and 1% by dry mass of the soil. The 7 day strength of the fully cured composites was determined by a series of unconfined compression tests. The results shows that optimum strength of 3.5 MPa was mobilised by un-precompressed specimens at 0.75% fiber content. Pre-compression with 10% UCS showed maximum strength of 2.8 MPa at 0.25% fiber content whereas 20% UCS indicated optimum strength of 3.04 MPa at 0.25% fiber content. In comparison, pre-compressed specimens exhibited lower strength values than un-precompressed specimens. Fiber inclusions significantly improved ductility of the stabilised soil.

3.2 Lime Stabilisation By Ion Migration

Rao and Venkataswamy (2002) examined the effect of lime pile in compacted expansive soil. This study has been conducted as a laboratory experiment having lime pile (75mm) installed in a circular tank (305mm dia). Calcium and hydroxyl ion migration surrounding the soil increases the pH and salinity of soil. Ion migration reduces the plasticity and swell potential of soil. The unconfined compressive strength of soil was increased to 90%.

Rajasekaran and Rao (2002) investigated the lime induced permeability changes in the permeability and engineering behavior of different lime column treated soil systems. Marine clay treated with lime columns shows an increase in permeability up to a maximum value of 15–18 times that of untreated soil with time. The shear strength of the treated soil show an increase up to 8–10 that of untreated soil within curing period of 30–45 days. The permeability has been increased up to 10–15 times that of untreated soil, whereas the strength of the soil has been higher by 8–10 times that of untreated soil. Further, consolidation tests show a reduction in the compressibility up to 1/2– 1/3 of original values. The test results revealed that both lime column and injection techniques could be used to improve the behaviour of underwater marine clay deposits.

Chand and Subbarao (2007) studied about the application of suitable in situ stabilization method to improve the geotechnical properties of the ash deposit as a whole, converting it to a usable site. In this study, a technique of in-situ stabilization by hydrated lime columns was applied to large-scale laboratory models of ash pond deposits. Samples collected from different radial distances and different depths of the ash deposit were tested to study the improvements in the particle size distribution, water content, dry density, pH, unconfined compressive strength, , hydraulic conductivity, and leachate characteristics over a period of one year. The in-situ stabilization by hydrated lime column has been found effective in increasing the unconfined compressive strength and reducing hydraulic conductivity of pond ash deposits in addition to modifying other engineering properties. The strategy has additionally turned out to be helpful in diminishing the contamination potential of the ash leachates, thus relieving the adverse environmental effects of ash deposits.

Larsson *et al.* (2007) evaluated property changes in laboratory-prepared kaolin surrounding lime–cement columns. The parameters investigated included geotechnical parameters such as undisturbed undrained shear strength, remoulded shear strength, water content, and Atterberg limits. In addition the exchangeable Ca^{2+}, Na^{+} and K^{+} ion concentrations were assessed. Four types of small-scale lime–cement columns were manufactured using different methods and binder ratios. Tests were performed 7, 14, 30 and 90 days after installation. The results shows that the undrained shear strength properties in the surrounding kaolin were significantly affected by the migration of Ca^{2+}, Na^{+} and K^{+} ions. An increase in the Na+ and K+ ion concentrations in the front of the migrated Ca^{2+} ions was observed. The tests illustrate that, under the experimental conditions chosen, the remoulded undrained shear strength decreased in a thin zone as a result of the migrated Na^{+} and K^{+} ions. The magnitude of the strength loss depended on the binder blending ratio in the lime–cement columns.

Singh *et al.* (2016) studied the efficacy of lime column in improving the geotechnical characteristics of sedimented ash deposits. In this experimental investigation, large scale laboratory model of sedimented ash bed is prepared with a centrally installed lime column. After the curing periods of 30, 90, 180 and 365 days, the undisturbed specimens are collected from different radial distances like 15, 25, 35 and 45 cm and at various depths of 10, 30, 50 and 70 cm to study the improvement in various geotechnical properties. In addition, X-ray diffraction and scanning electron microscopy tests were done in order to study the effect of curing period on hydration products, strength and hydraulic conductivity of the stabilised specimens. The study indicates that lime column treatment is an effective means of increasing the unconfined compressive strength and reducing hydraulic conductivity of ash deposits along with modifying other geotechnical parameters including water content, dry density and shear parameters.

Abiodun *et al.* (2016) researched to examine the performance of the lime pile application, a deep chemical stabilization method to improve the engineering characteristics of marine soil deposits. By using a laboratory scale model, the marine soil sample was compacted into soil blocks in circular steel test tanks, with the installation of lime piles in them. An experimental program examined the effect of the lime piles on the physical and geotechnical properties of the soil considering the curing periods and lime pile radial distances. Test results showed that the clay fines, linear shrinkage, compressibility and swelling pressure decreased, while the permeability, preconsolidation pressure, and stiffness increased significantly with an increase in curing periods and within a close distance to the lime piles.

3.3 Stabilisation by lime precipitation

Bhuvaneshwari *et al.* (2010) studied the stabilization of soil through the physico-chemical reactions assisted by ion migration. In this study, chemical additives (NaOH and $CaCl_2$) which intrinsically forms $Ca(OH)_2$ in the soil are used, and brings about the same reactions as of lime treated soil. The calcium hydroxide formed combine chemically with the soil particles together and form a cemented mass and results in pozzolanic reactions at any depth of injection. The change in Atterbergs limits, UCC and pH were similar to samples that are directly mixed with corresponding percentages of lime. This was further substantiated with the results from EDAX and SEM analysis.

Thyagaraj *et al.* (2012) has studied the precipitation of lime in soil by successive mixing of $CaCl_2$ and NaOH solutions with the expansive soil in two different sequences. The results indicated that in situ precipitation of lime in soil by sequential mixing of $CaCl_2$ and NaOH solutions developed strong lime-modification and soil-lime pozzolanic reactions. The lime-modification reactions together with the poorly developed cementation products reduced the swelling potential as well as the plasticity index, and increased the unconfined compressive strength of the clay sample cured for 24 h. Results also show that the sequential mixing of expansive soil with $CaCl_2$ solution followed by NaOH solution is more effective than mixing expansive soil with NaOH solution followed by $CaCl_2$ solution.

4. CONCLUSIONS

Lime generally improves the engineering performance of soils. A series of experiments through careful variation of different parameters should be carried out to develop an understanding of the possible mechanisms involved. Lime, can be used to treat a range of soil types, either alone or in combination with other materials. The mineralogical properties of the soils will determine their degree of reactivity with lime and the development of the ultimate strength of the stabilized layers. Lime in the form of quicklime (calcium oxide, CaO), hydrated lime (calcium hydroxide, $Ca[OH]_2$), or lime slurry can be used to treat soils either by direct mixing, ion migration or by lime precipitation.

Lime acts rapidly and improves various properties of soil such as carrying capacity of soil, resistance to shrinkage during moist conditions, swelling, reduction in plasticity index, and increase in CBR value and subsequent increase in the compression resistance with the increase in time. The reaction is very quick and stabilization of soil starts within few hours. Lime is used as an excellent soil stabilizing materials for highly active soils or expansive soils which undergo frequent expansion and shrinkage.

REFERENCES

[1] A. A. Amadi and A. Okeiyi (2017), "Use of quick and hydrated lime in stabilization of lateritic soil: comparative analysis of laboratory data", "International journal for geo-engineering, Vol- 8 pg: 1 -13.

[2] Abiola Ayopo Abiodun and Zalihe Nalbantoglu (2016), "Lime pile techniques for the improvement of clay soils", "Canadian Geotechnical Journal", pg: 1-9.

[3] Aref al-Swaidani, Ibrahim Hammoud, Ayman Meziab (2016), "Effect of adding natural pozzolana on geotechnical properties of lime-stabilized clayey soil", "Journal of Rock Mechanics and Geotechnical Engineering", Vol-8, pg:714-725.

[4] Bhuvaneshwari S, Thyagaraj T, Robinson R.G, Gandhi, S.R (2010), "Alternative Technique to Induce Faster Lime Stabilization Reaction in Deeper Expansive Strata "Indian Geotechnical Conference – 2010", pg:609-612.

[5] D. I Boardman, S. Glendinning and C. D. F. Rogers (2001), "Development of stabilisation and solidification in lime-clay mixes", Vol-6, pg:533-543

[6] Eduardo Garzon, Manuel Cano, Brendan C.O Kelly, Pedro J. Sanchez-Soto (2016), "Effect of lime on stabilization of phyllite clays", "Applied Clay Science".

[7] F G Bell (1996), "Lime stabilization of clay minerals and soils", "Engineering geology", Vol-42, pg: 223-237.

[8] Habiba Afrin (2017), "A Review on Different Types Soil Stabilization Techniques", "International Journal of Transportation Engineering and Technology", Vol-3, pg:19-24.

[9] Innocent Kafodya, F. Okonta (2018), "Effects of natural fiber inclusions and pre-compression on the strength properties of lime-fly ash stabilised soil", "Construction and Building Materials", Vol-170, pg: 737-746.

[10] Jun-Jie Zheng, Sari W. Abusharar, Xian-Zhi Wang (2008), "Three-dimensional nonlinear finite element modeling of composite foundation formed by CFG–lime piles", "Computers and Geotechnics", Vol-35, pg:637-643.

[11] M. Yıldız, A.S. Sogancı (2012), "Effect of freezing and thawing on strength and permeability of lime-stabilized clays", Vol-4, pg: 1013-1017.

[12] Mahdi Keramatikerman, Amin Chegenizadeh, Hamid Nikraz (2016), "Effect of GGBFS and lime binders on the engineering properties of clay", "Applied Clay Science", Vol-132, pg: 722-730.

[13] Rajasekaran G and Narasimha Rao, (1996), "Lime migration studies on marine clay", "Ocean Engineering", "Vol-23, pg-325-355.

[14] Rao, S.M. and Venkataswamy B.V (2002), "Lime pile treatment of black cotton soils", "Ground Improvement", Vol-6 (2),pg: 85-93.

[15] Singh S. P., Roy N. & Sangita S. , (2016), "Strength and hydraulic conductivity of sedimented ash deposits treated with lime column", "International Journal of Geotechnical Engineering", pg-1-8

[16] Soheil Soheil Jahandari, Mohammad Saberian, Farzad Zivari, Jie Li, Mojtaba Ghasemi & Ramin Vali, (2017), "Experimental study of the effects of curing time on geotechnical properties of stabilized clay with lime and geogrid", "International Journal of Geotechnical Engineering", pg-1-12.

[17] Stefan Larsson, Mirja Rothhämel, Gunnar Jacks (2009), "A laboratory study on strength loss in kaolin surrounding lime–cement columns", "An International Journal on clay and clay minerals" (ELSEVIER), Vol-44, pg-116-126.

[18] Sudeep Kumar Chand and Chillara Subbarao, (2007), "In-Place Stabilization of Pond Ash Deposits by Hydrated Lime Columns", "Journal of Geotechnical and Geoenvironmental Engineering", Vol-133, pg-1609-1616.

[19] Thyagaraj T., Sudhakar M. Rao, Sai Suresh P., and U.Salini, (2012), "Laboratory Studies on Stabilization of an Expansive Soil by Lime Precipitation Technique", "Journal Of Materials In Civil Engineering", Vol-24, pg-1067-1075.

[20] TS. Umesha, S.V.Dinesh and P.V.Sivapullaiah (2013), "Lime to improve the unconfined compressive strength of acid contaminated soil", " International Journal Of Geology", Vol- 7, pg:49-57

[21] Wanjiong Wu, Shouyun Liang, Fanyu Zhang, Xude Yan and Jianji Zhou (2014), "Feasibility analysis of loess slope improved by lime pile", "Landslides science for a safer geoenvironment, Springer international publishing Switzerland", Vol-2.

[22] Xiangjun Pei, Fanyu Zhang, Wanjiong Wu, Shouyun Liang (2015), "Physicochemical and index properties of loess stabilized with lime and flyash piles", "Applied Clay Science", Vol-114, pg: 77-84.

[23] Z. Metelkova, J. Bohac , R. Prikryl , I. Sedlarova(2012), "Maturation of loess treated with variable lime admixture: Pore space textural evolution and related phase changes", "Applied Clay Science", Vol- 61, Pg:37-43.