Environmental Effects of Lime on Mechanical Characteristics of Stabilized Closed-texture Soils

S. Boudaghpour, F. Majdzadeh

***Abstract*—** Many closed-texture soils due to natural characteristics of the constituent minerals or geological processes of their formation, in contact with water are soft and swollen. If the origin of soil be marl, saturating may cause weakening of soil mass, reducing shear strength, land sliding on steep piles and ultimately destructive pressures to adjacent structures. When the type of soil cemented materials is water soluble salts, any water flow causes leaching of salts and will result soil divergence, piping phenomenon on steep piles or severe surface erosion. In this case using additives as natural and artificial pozzolan, lime and polymeric materials, is one way to stabilize the soil. in addition to mechanical reinforcement of soil, each of these materials have environmental and physical effect on environment, accordance with their chemical properties. In this paper, the effect of lime on geotechnical characteristics of soil-lime mixtures is surveyed. To do this, soil mechanical tests including Atterberg limits, Proctor compression, Not-confined compressive strength and Direct shear were used. Undesirable characteristics of soil can be improved and its behaviors can be modified by increasing amounts of lime and cement in lime-soil mixtures (within this survey). The percent of selected weight is between 0-14 (wider domain than what is practically used in projects). In this way, the erosion of closed-texture soil can be prevented and favorable environmental effects can be achieved.

***Keywords*—** Atterberg Limits, Environmental Effects, Lime, Soil Stabilization, Uniaxial Resistance.

I. INTRODUCTION

Clay soils have a relatively high resistance in the dry state. But because of clay desire to absorb and hold water, as water absorption intensity lose their strength. Hence to use of these soils in humid and rainy areas specific arrangements should be considered. Natural soil at construction site is not always appropriate completely for weight bearing of desired structure. For example, natural soil in granular deposits can be very loose, it can also show high amount of immediate consolidated settlement. So, it’s necessary to compact the soil before establishing the building. Compacting leads to increasing the special weight and shear resistance of the soil [4].

Siamak Boudaghpour, Member of Civil Eng., Dep., Khaje Nasir Toosi University of Technology, Tehran, I.R.Iran (corresponding author to provide phone: +989124258802; e-mail: Boudaghpour@yahoo.com).

Farhad Majdzadeh, Master of Water Resource Management, Khaje Nasir Toosi University of Technology, Tehran, I.R.Iran (e-mail: fmajd@gmail.com)

Sometimes the upper layer of the soil is unfavorable, so it must be removed and replaced with a better soil on which the foundation can be established. Selected soil for replacement must be also compacted to reach to the adequate stability. Sometimes there are soft saturated layers in shallow depth. Based on the foundation load and clay layer thickness, significant settlement in structure is seen. To avoid such settlement, certain techniques must be applied to improve the soil condition. Characteristics of weak soils can be improved and basically changed by adding stabilizer materials such as lime, cement, tar, chlorine and calcium [2].

Improving soil characteristics by using additive materials is called stabilization. Selecting stabilizer type depends on different factors such as soil type, regional weather conditions, traffic rate and construction operation cost. There are wide extent of closed-texture soils in our country and most of time we are obliged to implement many of the projects on these soils. So, the importance of stabilizing the closed-texture soils, especially clay soils, is clear. Using lime to stabilize and reinforce the soil, in form of lime and soil powder or grout of lime and soil, along with all favorable mechanical effects, may also create unintended effects. This study examined the mechanical properties of a soil-lime mixture and its environmental impacts.

The beginning academic study of using additives to improve the strength properties of clay is returned to 1960. It was observed by adding lime or cement to clay, strength properties such as shear strength and compressive strength is greatly improved. Afterwards extensive research by geotechnical scientists conducted about the effects of other additives to closed-texture soil. Chen (1975) made a study about the amount of lime required for stabilization of clay soils and concluded that the range of lime required for stabilization of clay soils is 2 - 8 percent [5]. Diamond (1975) with study on strength properties of the improved clay soils concluded that this soil can be used for runways foundation, construction of dams and also at points of hydraulic structures where erosion is possible [6]. Mitchel (1976) researches on Compressive characteristics of modified soils led to this result that if exist the interval between sample preparation and compression test lead to reduce the uniaxial resistance [7]. Hammond (1992) arranged studies about improvement and increasing the resistance of clay soils stabilized with lime and achieved that the resistance of clay soil- lime mixture is so that it can be used for stabilizing the side slopes of channels and also for making foundation of structure which the applied load on the base is not so much [8]. Croft (1996) also found that adding lime to closed-texture soils decreases swelling potential, liquid limit, plasticity index and the maximum dry density and increases optimum moisture content, the contraction level and resistance [9]. Osinubi (2006) Studied about the effect of compaction force, ash and lime on uniaxial resistance and compression properties of clay soils and concluded that the highest axial resistance is achieved when mixing the clay with lime occurs immediately after compaction [10].

II. Stabilization

Soil Stabilization refers to improve its physical and engineering properties, to provide a set of predetermined targets. Soil stabilization is done in various ways such as mechanical, chemical, physical, biological (plant growing) and electrical methods. The main objectives for soil stabilization are: Increasing the bearing capacity of soil (vertical loads, horizontal loads…), reducing soil settlement, reducing cohesiveness in the soils with high rate of cohesion (such as clay), increasing cohesiveness in the soils with low rate of cohesion (such as aeolian sand), reducing the percentage of water absorption and preventing the soil swelling, reducing the construction cost (soil transmission), accelerating road construction operations (less carrying and more density capacity), stability against atmospheric agents such as repetition of freezing and ice-melting, decreasing the thickness of pavement layers, plants not-growing on the path, decreasing deformability affected by loads, reducing the rate of dust caused by crossing vehicles, controlling swelling and shrinkage characteristics caused by moisture content changes.

III. Lime

Lime or calcium oxide [CaO] is a white porous solid which is derived from heating pure limestone at temperatures between 1100-1200 ℃ (Eq. 1). limestone or calcite [$CaCO_3$] is usually colorless and odorless and its hardness and density is 3 and 2.71 g/cm³ respectively.

$$CaCO_3 + 42.5\ kcal \rightarrow CaO + CO_2 \quad (1)$$

The quality of the final product (lime) depends on the quality [$CaCO_3$] and thermal process. Calcite is one of the main minerals sedimentary and metamorphic rocks and it's the most abundant mineral in the mineralized veins. Limestone rarely can be found in pure lime form in nature. Significant impurities of limestone include magnesium, silica, aluminum and manganese.

The limes which are used for stabilizing fine-grained soils are: Calcium hydroxide or blown lime [$Ca(OH)_2$], fast harden lime (CaO), mixture of calcium hydroxide and dolomite.

Melting point and density of lime (quicklime) varies between 2580 to 2750 ° C and 1/3 to 3/3 g/cm³ respectively. Lime has a strong affinity with water, so that with absorption of water, while producing much heat (which is also dependent on the quality CaO), lead to evaporation of a certain amount of water and produces white powder which is called hydrated lime or blown lime (Eq. 2). Blown lime is also known as dead lime, Because in contact with water it does not react anymore.

$$CaO + H_2O \rightarrow Ca(OH)_2 + 15\ kcal \quad (2)$$

In general, it can be said that lime is more effective stabilizer [1,2]. In addition, adding lime in grout form will produce higher resistance in compared with its powder form. Although due to the high percentage of CaO, lime has greater effect than hydrated lime in soil stabilization and modification, but because of working with hydrated lime is much safer, its application is more common in the industry.

IV. Lime stabilization

Soil stabilizing by adding heated limestone products or calcium oxide or calcium hydroxide is called lime stabilization. Basically Lime is not appropriate for stabilization of soils containing more than 2% organic materials and more than 0.5 % water-soluble sulfate, although usually reacts with most of soils which their plastic index is between 10-50 PI. Reacting soils with PI below 10 and lime needs pozzolan. Generally, coal ash is used to do this reaction. As defined ASTM, Pozzolanic substances are silica or silica aluminate materials, which are not naturally adhesive, but at ordinary temperature and in the presence of moisture reacts with calcium hydroxide to form compounds that have cementitious and adhesive properties. Other pozzolans used for increasing lime stabilization are: blast furnace slag and bloated clay. Lime stabilizing of heavy clays produces more fragile soil which can be compacted and used more easily. Although a lower maximum density is obtained, lime reaction with monte merilunit clays is quicker than kaolinite clays. In fact, needed time difference for these two reactions is about two weeks.

V. Determination of appropriate lime rate

Adding Lime up to the optimum percentage can improve soil characteristics. If lime quantity be more than optimal percentage, there is amount of unused Lime in environment which decreases resistance. That's why finding the optimum rate is considered an important issue for adding to the soil.The main purpose in soil stabilized plan with lime is determination of appropriate rate for the soil with certain characteristics. In other words, the key variable in soil stabilization plan is lime percentage, because the lime soil characteristics assumed to be constant.The lime rate required is determined based on weight percentage of dry soil. The appropriate lime percent for soil stabilization is percentage which satisfies intended liquid limit or plastic index. Bell (1996) has found the optimum lime percent for soil stabilization is between 1% to 3% of the dry density of the soil and further increase will have not a significant impact on plasticity characteristics but resistance increases [11]. Adding more than 3% lime to silty clays modifies heavy clay soils and too heavy ones. For stabilizing silty clays, 3-8% lime is suggested. In addition, it has been stated that 1% lime (in compared with soil dry density) for each 10 percent clay in soil is a good guideline [2]. There are several ways to determine the optimum lime percentage, such as the methods: PH, Plasticity Index, California Bearing Ratio (CBR), AASHTO and unconfined compressive strength test. In this study has been used unconfined compressive strength test. The mentioned test has been standardized according to instructions ASTM-D 2166 (AASHTO-T 208) and has many applications in geotechnical activities. In this method for determining the optimum lime rate, The amount of lime that makes the maximum uniaxial strength is considered in the soil - lime mixture.

VI. CHEMICAL REACTIONS IN SOIL-LIME MIXTURE

Several factors affect the reaction of clay and lime. For instance can mention to amount of clay. Previous researches confirm that stabilization with lime affects for Soils which amount of their clay minerals be enough for pozzolanic reaction. It means that must be at least 10% of the clay minerals in soil [21]. In some reference stated that at least 2.5% of the soil passes through sieve No. 200 (0/075 mm) in the USCS classification so stabilization with lime to be effective. PH rate of environment is also important, so that PH value should be at least greater than 10 to reaction occurs between lime and clay [7]. In another reference, the minimum PH value for the reaction is expressed 12.4 [8]. In addition, the type and concentration of cations in the environment and type of clay minerals influence on clay-lime reaction [12]. Two reactions occur when lime is added to the moist closed-texture soil: Short-term reactions and Long-term reactions. Short-term reactions involving cation exchange, flocculation and carbonation reactions .Also pozzolanic and resistance reactions included in long-term reactions. Approximately all closed-texture soils show the cation exchange reaction during a short period of time after mixing with lime and water. Cation exchange occurs between exchangeable clay cations (monovalent cations such as sodium) with lime calcium ions and as a result clay particles close together. This process called flocculation. In carbonation reaction lime combines with carbon dioxide gas in the air which causes lime back to the limestone non-reactive mode. But in second group reactions, namely long-term reactions (pozzolanic), when lime is added to the wet soil, hydrolyzed to calcium and hydroxide ions (Eq.3). These substances increase the resistance and compressibility of the clay soils [12,13]. By increasing amount of lime, OH- and consequently soil PH will increase. By increasing PH, dissolved alumina and silica in the soil and during pozzolanic reactions with the calcium in lime, create cementitious gels that called calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) (Eq. 4,5).

$$Ca(OH)2 \rightarrow Ca2_{+} + 2OH- \quad (3)$$

$$Ca2_{+} + 2OH- +SiO2 \rightarrow CaO.SiO2 + H2O \text{ (CSH)} \quad (4)$$

$$Ca2_{+} + 2OH- +Al2O3 \rightarrow CaO.\ Al2O3 + H2O \text{ (CAH)} \quad (5)$$

Combining operation is also important. Delay in operation, after exposing the lime to the air, will lead to reduction in the effects of lime carbonation. So, it's desirable to do the combining process as soon as possible, definitely before 24 hours, after exposing the lime to the air.

VII. CHARACTERISTICS OF STABILIZED SOILS BY LIME

In most cases, impact of lime on plastic characteristics of clay soils is immediate. Strength of soil-lime mixture depends on some factors such as soil type and rate of added lime. Generally, the plastic characteristics of all closed-texture soils get better quality after combining with lime. However, adding lime to every type of soil doesn't give rise to considerable increase in its resistance. Lime stabilized soil has got the less maximum dry density and greater optimal moisture percentage in compared with not-stabilized soil. The more lime for stabilizing soil, the greater this difference will be. As mentioned before, adding lime to soil leads to reducing plastic characteristics of the soil so that in some cases soil-lime mixture gets completely non-plastic. The soils with higher clay content or greater plastic domain require greater rate of lime to reach to non-plastic state. Another effect of adding lime is increase in uniaxial resistance of the soil. After adding lime to the soil, usually soil resistance considerably increases. Immediate increase in soil resistance makes easier the implement operations and machines movement on the plastic cohesive soils and improves the soil quality for stabilization. In cases where the immediate resistance of soil-lime mixture is desired, curing the samples is not needed and after compression can be performed the required tests on the specimens. If the immediate resistance of mixture is not intended, the soil samples stabilized with lime should be cured during 28 days and at 23 °C, prior to performing the required tests. Also conditions of accelerated curing, involves curing the specimens for 48 hours at 50 °C. It is recommended to prevent of decreasing the samples moisture and carbonate of lime, curing specimens performs in plastic covers or closed containers. Soil resistance doesn't increase in line with increasing lime rate. In fact, adding too much lime leads to decreasing resistance. The reason of decreasing resistance is that lime doesn't have considerable cohesion and internal friction by itself. Optimum rate of lime is in a range between 4/5-8%. Curing time is one of the effective factors in resistance of lime stabilized soils. Upper temperature will accelerate curing and gives rise to higher rate of resistance. If the temperature comes below, the soil-lime reaction will completely stop or be delayed. Resistance of lime stabilized soil decrease with increasing moisture. Even 3 months after stabilization, shear resistance of soils with high amount of saturation moist content remains low. It means, the soil-lime mixtures which are compacted in a moisture percentage higher than optimum, in a short time after curing, reach to higher rate of resistance in compared with the soils which are compacted in a moisture percentage less than optimum.

VIII. PROCEDURE

The lime used in this study is Alborz Industrial blown lime that is available in bags of 25 kg with non-vibrated density 550 kg/m³ in the market. In this study, some specimens prepared with the characteristics mentioned in table 1. A series of soil mechanical tests were done, including Atterberg limits, not-confined compressive strength and direct shear. The soil used in these tests, under a uniform standard (USCS), was classified as silty clay with low plastic characteristics (CL). Particle density tests, hydrometer, Atterberg limits and proctor compaction were done on this soil. In order to stabilize, cement type II (Abyek Cement Factory) was used. All of the compressive strength and direct shear tests were done on the specimens with 100% density and optimum moisture content. To achieve this goal, all of the made mixtures, were used in proctor test in order to determine the maximum special dry weight and optimum moisture. Made specimens were put into two plastic bags and were looked until the desired age. Then, in different ages, not-confined compressive strength and direct shear tests were done.

Table1. Different components used in this study

Abbreviated name	Mixture Characteristics
S + 2L	Natural soil + 2% lime
S + 6L	Natural soil + 6% lime
S + 10L	Natural soil + 10%lime
S + 14L	Natural soil + 14% lime

IX. LIQUID LIMIT AND PLASTIC LIMIT TESTS

To avoid the effect of time on the results of these tests, the onset time of the first test was determined 1 hour after adding water and the last test time was determined about 2 hours after adding water to the mixture. For each kind of mixtures, liquid limit and plastic limit tests were done 3 times. Plastic index of natural soil was 12 and the liquid limit was 32. Figure 1 shows the effect of adding lime on liquid limit and plastic index of soil-lime mixtures. According to these figures, increasing amount of the lime leads to descending plastic index of the mixtures. The rate of liquid limit in the mixtures didn't change so much and was approximately constant.

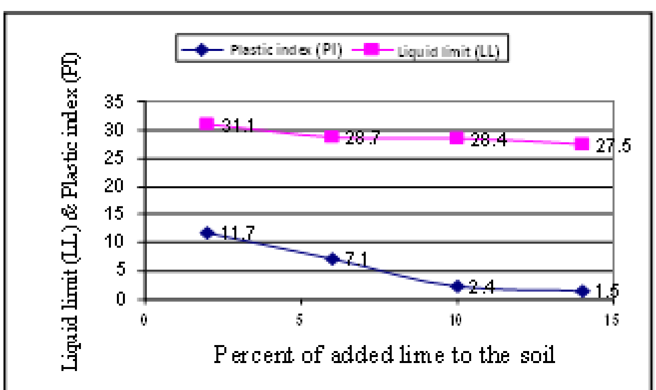

Fig.1 Effect of adding lime on liquid limit and plastic index of soil- lime mixtures

X. NOT-CONFINED COMPRESSIVE STRENGTH TESTS

On each of 9 different combinations, at age 0, 7, 14 and 28 days, compressive strength test was done. Device movement speed was selected 1/6 mm/min. At age 0 days, all specimens, which their fracture was like a bulge, except for natural soil, were ruptured in a skewed form. To control the results, for each combination two cylindrical model was made and tested. Figure 2 shows the effect of lime on not-confined compressive strength of 28-day specimens. According to this figure, in a soil-lime mixture, the maximum compressive strength of soil after reaching to an increase of 350% came down from 2.12 kg to 7.5 kg/cm². In a mixture with 14% lime, not-confined compressive strength with a 15% reduction came to 6.5 kg/cm².

The graphs in figure 2 show the effect of lime on not-confined compressive strength of maximum soil mixtures. In this graph, we can see that the not-confined strength of soil-lime mixture after a rise has encountered with a decline. In not-confined strength curve, there's a peak in the lime percentage. The peak represents the optimum percentage of lime in the mixture. According to Figure 3, rate of optimum percentage of lime is determined 9.6%.

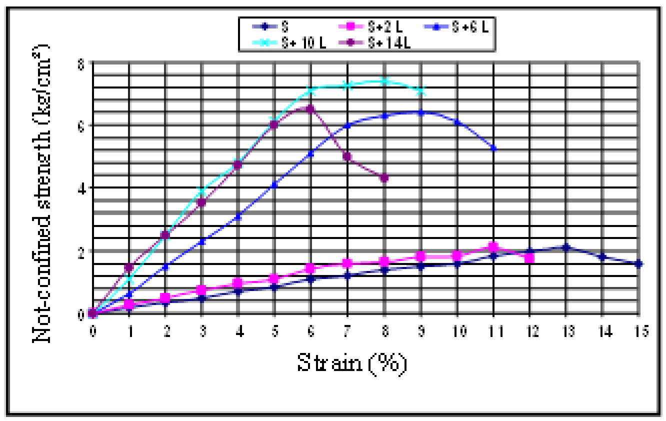

Fig.2 Effect of lime rate on 28-day not-confined compressive strength

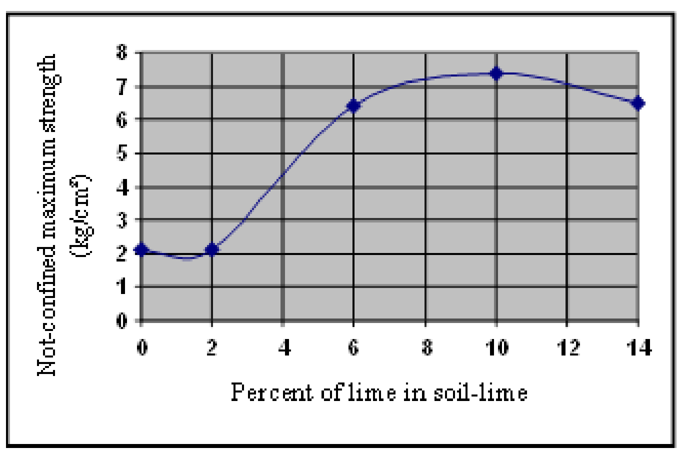

Fig.3 Effect of lime on the compressive strength (not-confined) of maximum 28-day soil-lime mixtures

XI. Direct Shear Tests

To perform these tests, the device speed was determined 1 mm/min, and vertical stress applied in all tests was selected 1 kg/cm². To control the results of each combination, 4 shear samples were made and tested. According to figures 7 and 8, adding cement and lime leads to raising the shear elastic coefficient and brittling 28-day samples. The results of these tests are qualitatively very similar to not-confined strength tests and confirm those results. The results of these tests are qualitatively very similar to not-confined tests and confirm those results.

Figure 4 is very similar to figure 2 and confirms its results. This figure shows that the maximum shear stress in the soil-lime mixture, after a rising, declines and in the maximum shear stress curve, a peak occurs in the lime percentage. This peak represents the optimum maximum percentage of lime in the mixture. According to Figure 5, rate of optimum percentage of the lime equals to 8.9%.

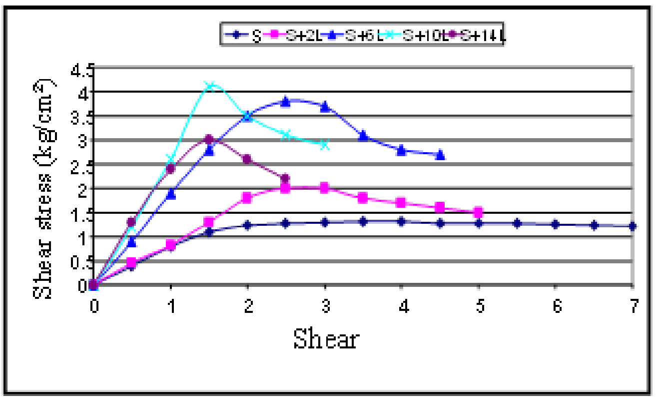

Fig.4 Effect of lime rate on resistance of 28-day mixtures in direct shear test

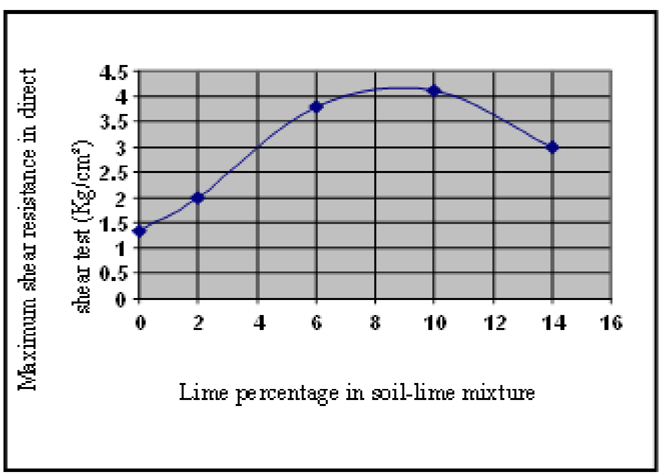

Fig.5 Effect of lime rate on shear resistance of the maximum 28-day lime mixtures
(Vertical stress of 1 kg/cm²)

IIX. Conclusions

- Not using of improvement and stabilization methods causes to be carried the required materials over long distances. In these circumstances, the cost of performance with respect to high volume of selected materials will be too expensive. So soil improvement is a good choice which is often the most economical method for solving geotechnical problems.
- Adding lime to the clay soil in the soil-lime mixture leads to declining in plastic index. So efficiency of soil-lime mixtures is less than the soil without additives. Additives have undesirable chemical environmental effects.
- Adding lime to clay soil leads to a rising and then declining in not-confined compressive strength and shear resistance of soil-lime mixtures.
- The optimum percentage of lime in the soil-lime mixtures which prepared with studied soil was determined about 9%.

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