Effect of Hydrated Lime Stabilization on Consistency, Shear Strength and Compaction Properties of Sulaimani CL Soil

Nihad Salih[1] and Tavga Aram Abdalla[2]

[1]Affiliation not available
[2]University of Sulaimani

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Abstract

Cohesive soils present difficulties in construction projects because of usually contain expansive clay minerals. However, the engineering properties of soils can be stabilized by different techniques. The aim of the research is to discover the influences of using hydrated lime on the consistency, compaction, and shear strength properties of clayey soil samples from Sulaimnai city, northern Iraq. The proportions of added hydrated lime are 0%, 2.5%, 5%, 7.5% and 10% to the untreated soil sample. The results showed significant effects on the engineering properties of the selected soil sample and developed its strength. The soil's liquid limit, plasticity index, and optimum moisture content were decreased with the increase of hydrated lime percent. While the soil's plastic limit and maximum dry density were increased. Also, the soil's unconfined compressive strength was significantly increased with the hydrated lime content increase. Hence, hydrated lime is successful and can be considered as an effective material to improve the strength and consistency properties of the cohesive soils in Sulaimani city.

1. Introduction

In the field of civil engineering, various methods are adopted to improve the geotechnical properties of soils in order to meet the requirements for stability and maintenance cost reduction. Clayey soil stabilization by various additives may be one of these methods, because of the substitution of inappropriate soils by adequate ones has become increasingly expensive and ecologically unsafe. Besides that, stabilization by cement is not preferable due to its growing cost and environmental concerns related to its production (Al-Swaidani et al., 2016). Luting materials such as lime have been successfully employed in the geotechnical engineering discipline for soil stabilization purpose and mechanical properties improvement, especially for clayey and silty soils. Lime is widely used in civil engineering applications such as road construction, embankments, foundation slabs and piles (Al Rawas and Goosen, 2006).

The carried out studies in the literature show that the addition of lime increased the optimum moisture content and strength, and reduce the plasticity index and maximum dry density of the soil (Guney et al., 2007; Croft, 1967; Ola, 1977; Rahman, 1986; George et al., 1992; Bell, 1996; Gay and Schad, 2000; Hossain et al., 2007). On the same matter, extensive studies have been carried out on the stabilization of clayey soils using lime (Basma and Tuncer, 1991; Kassim and Chern, 2004; Mohamed et al., 2009; Sherwood, 1993). As investigated by Sabry (1977), many significant engineering properties of soft soils also can be beneficially modified by lime treatment, as lime decreases the plasticity index, increases the workability and shrinkage limit, reduces shrinkage cracking, eliminates almost all swelling problems, and increases soil strength.

In another way, several researchers (Al-Rawas et al., 2005; Goswami and Singh, 2005; Rahman, 1986; Muntohar and Hantoro, 2000; Attoh-Okine, 1995; Nalbantoglu, 2006; Lasledj and Al-Mukhtar, 2008; Osula, 1996; Ola 1977; Bagherpour and Choobbasti, 2003; Kavak and Akyarli, 2007; Manasseh and Olufemi, 2008;

Okagbue and Yakubu, 2000; Ansary et al., 2006) found that in most cases, the effect of lime is more or less instantaneous on the plasticity properties of the clayey soils.

On shear strength characteristics, hence in some studies (Lin et al., 2007; Chen and Lin, 2009) postulated that the observed shear failure mode of stabilized soil samples with lime is similar to brittle materials. Moreover, some researchers (Consoli et al., 2012; Calik et al., 2014) found that the soil strength properties were greatly improved after lime treatment. According to the study of Consoli et al. (2012 and 2014), the decrease of pores and lime volume increase are directly responsible for the increase of soil-lime mixture strength.

This paper presents the effect of hydrated lime on the Atterberg limits, compaction characteristics, and unconfined compressive strength of Sulaimnai city, Northern Iraq CL soil, which classified according to the unified soil classification system (USCS). All tests were conducted in accordance with the ASTM standards (1990 - 2000).

Aim and objectives of the study

The major required goal of this study is to provide more insight on the effects of lime stabilization on the maximum dry density (MDD), optimum moisture content (OMC), Atterberg limits, and unconfined compressive strength of Sulaimani city CL soil.

The specific objectives cover the following points:

- Investigation the effect of lime on plasticity of CL soil.
- Evaluation the factors affects MDD and OMC such as hydrated lime amount.
- Investigation the effect of lime content on the unconfined compressive strength of CL soil.

2. Experimental Investigation

2.1 Used Materials

2.1.1 Soil

The used soil in this study was obtained from a site, namely Barika soil, situated in Sulaimani governorate, northern Iraq. The studied natural soil is collected at a depth of 0.5 to 1 m from the natural ground level, and is normally consolidated clay. The undisturbed and disturbed soil sample were excavated, placed in plastic bags, and transported to the geotechnical laboratory for testing. Geotechnical laboratory tests were performed on the soil to determine its geotechnical properties. The obtained clayey soil sample was light brown in color, and is composed of some clay. It can be defined as low plasticity soil according to the Unified Soil Classification System (Akbulut, 1999; Kalkan, 2003; Kalkan and Bayraktutan, 2008, Rashed et al., 2017). Extreme precautions were taken during soil sampling to keep the collected soil samples in their natural moisture content and field density conditions. The particle size distribution curve of Barika clayey soil is shown in Figure 1. The tested sample can be classified, according to ASTM Standard (D422, 1990), as CL soil. The obtained properties of the untreated soil sample are summarized in Table 1. The selected lime for the study is hydrated lime, Ca $(OH)^2$, white color in the form of fine powder.

Table 1: Geotechnical properties of the tested untreated Barika CL soil sample.

Property	**Value**
Natural moisture content (%)	18.682
Color	Light Brown
LL (%)	44.632
PL (%)	19.46
PI	25.172
Specify gravity (G_s)	2.67
Maximum dry density (g/cm^3)	1.573

Property	Value
Optimum moisture content (%)	27.25
Unconfined compressive strength (KPa)	174.23
Soil classification (USCS)	CL

[CHART]

Figure 1: Grain size distribution of Barika CL soil sample.

2.1.2 Hydrated lime

The used hydrated lime in the current study is locally-available lime typically used for construction purposes. The chemical and physical properties of the used lime are presented in Table 2.

Table 2: Physical and chemical properties of the used hydrated lime.

Chemical Properties	**Chemical Properties**
CaO (%)	56.1
MgO (%)	0.13
Fe_2O_3 (%)	0.12
Al_2O_3 (%)	0.72
SiO_2 (%)	1.38
SO_3 (%)	0.21
L.O.I (%)	40.6
Physical Properties	**Physical Properties**
Percent passing sieve No.200 (%)	98
Surface Area (m^2/kg)	398
Specific gravity	2.78

2.2 Methods

The collected soil sample was divided into five equal parts with the same natural properties. Then, each part was mixed with 0%, 2.5%, 5%, 7.5% and 10% of hydrated lime, by the respective dry weight of the soil sample and then the required moisture content was added. The mixtures were stored in waterproof containers for 24 hours to allow for homogeneity and mature. Particle size distribution and specific gravity were determined for the untreated soil sample in the laboratory in addition to the Atterberg limits, standard Proctor compaction and unconfined compression tests. These laboratory tests were conducted on the untreated soil and the treated soil samples, respectively.

2.2.1 Atterberg limits tests

Liquid limit (LL), plastic limit (PL) and plasticity index (PI) were obtained following the method given in the ASTM D4318 (2000). Variations in the plasticity index of untreated clayey soils before and after addition of hydrated lime were then studied. The air-dried soil sample (passing through No. 40 sieve) was initially mixed with the required quantity of hydrated lime in a dry state. De-ionized water was added to the soil-hydrated lime mixture. To let the water permeate through the soil mixture, the paste was allowed to stand in an airtight container for about 24 hours before testing in the laboratory. After that, the paste was remixed with the stabilizer thoroughly for at least 15 min before performing the first laboratory test. The plastic limit tests were performed on the same mixture prepared for the liquid limit test. Both of liquid and plastic limit tests were conducted at room temperature.

2.2.2 Compaction tests

The method given in the ASTM D698 (2000) was applied to determine the maximum dry density (MDD) and the optimum moisture content (OMC) of the soil samples. The soil mixtures, with and without hydrated lime, were thoroughly mixed for one hour before performing compaction tests. De-ionized water was added to the soil mixture. The first series of compaction tests were aimed at determining the compaction properties of the untreated soil samples. The second serious of tests were carried out to determine the compaction properties of the treated soils with various amounts of hydrated lime.

2.2.3 Unconfined compression tests

Unconfined compressive strength tests on compacted specimens were conducted according to ASTM D2166 (2000) on the chosen soil sample with various percentage of hydrated lime. Soil samples were cured in plastic bag to prevent moisture change. To prepare the samples for the unconfined compression test, the samples were remolded according to the field dry density derived from the compaction test (1.56 g/cm3) and the natural moisture content (18.682%). For each type of mixtures, the unconfined compressive strength value was obtained as the average of two trials of unconfined compression tests.

3. Results and Discussions

3.1 Results of consistency tests of untreated and treated Barika CL soil with hydrated lime

The Atterberg limits tests results regarding Barika CL soil and hydrated lime mixtures at various percentages are presented in Table 3. The reduction in liquid limit and plasticity index is a consequence of exchanges between the free calcium of the hydrated lime and the absorbed cations of the clay mineral. This leads to a decrease in the size of the diffused water layer encircling the clay particles. The decrease in the size of the diffused water layer facilitates closer contact between the clay particles resulting in flocculation/agglomeration of these particles.

Table 3: Consistency tests results of untreated and treated samples of Barika CL soil by hydrated lime.

Hydrated Lime Content (%)	LL (%)	PL (%)	PI
0	44.632	19.46	25.172
2.5	40.78	36.68	4.1
5	38.68	32.88	5.8
7.5	39.03	34.04	4.99
10	38	32.88	5.12

3.2 Results of unconfined compressive strength tests of untreated and treated Barika CL soil with hydrated lime

UCS tests were performed on the Barika CL soil samples treated with hydrated lime. The treated samples carried out at various percentages of hydrated lime as shown in Table 4. The UCS of hydrated lime-treated samples develops rapidly with the hydrated lime percentage increase until the optimum hydrated lime content is reached. The soil samples in this study exhibit a rapid initial increase in the UCS with the addition of hydrated lime. The added optimum percentage of the hydrated lime to the natural soil sample further increased its UCS values (from 174.231 kN/m^2 to 960.85 kN/m^2). In comparison, similar results have been observed by various researchers who studied soils UCS properties such as Elhassan (2006).

Table 4: Unconfined compression tests results of the untreated and treated Barika CL soil samples.

Hydrated Lime Content (%)	q_u (kN/m^2)
0	174.231
2.5	238.22
5	375.77
7.5	736.42

Hydrated Lime Content (%)	q_u (kN/m^2)
10	960.85

3.3 Results of compaction tests of untreated and treated Barika CL soil with hydrated lime

The results for the compaction tests performed on the untreated and treated Barika CL soil samples with hydrated lime were measured via using the standard proctor compaction method. The addition of lime at various percentages to the soil samples increases their maximum dry density and reduces their optimum moisture content for the same compaction effort as shown in Table 5 and Figure 2. A similar trend of behavior has also been observed for the case of hydrated lime treated clay in the study of Ingles and Metcalf (1972).

Table 5: Standard proctor compaction test results of the untreated and treated Barika CL soil samples.

Used Hydrated Lime Content (%)	MDD (gm/cm^3)	OMC (%)
0	1.573	27.25
2.5	1.635	25
5	1.66	23.27
7.5	1.714	20.25
10	1.785	17

[CHART]

Figure 2: Water content-density relationships from compaction tests for Barika CL soil stabilized with various percentages of hydrated lime.

4. Correlation of consistency, compaction and strength parameters with the degree of the used hydrated lime (HL)

4.1 Consistency properties

A good correlation was obtained between liquid limit as a function of hydrated lime content in the form of linear equation with the coefficient of determination R^2 equal to 0.8021 as shown in Figure 3 and the corresponding linear equation as follows:

LL (%) = 43.202 $e^{-0.015HL}$ (1)

The best relationship between plasticity index (PI) and used hydrated lime content, as compared to the plastic limit (PL) and used hydrated lime content can be seen in Figure 4 in the form of polynomial equations with the coefficient of determination R^2 equal to 0.8181 and 0.7204 respectively and the corresponding non-linear equations as follows:

PI (%) = 0.4559 HL^2 - 6.1279 HL + 22.578 (2)

PL (%) = -0.3634 HL^2 + 4.6023 HL + 21.805 (3)

[CHART]

Figure 3: Liquid limit relationship with the used hydrated lime content.

[CHART]

Figure 4: Plastic limit and plasticity index relationships with the used hydrated lime content.

4.2 Unconfined compressive strength (q_u)

The best trend line between q_u versus used hydrated lime content plot has given a high coefficient of determination R^2 equal to 0.9818 in the form of non-linear equation as shown in Figure 5 and the corresponding equation as follows:

Qu ($kN.m^{-3}$) = 163.65 $e^{0.1817HL}$ (4)

[CHART]

Figure 5: Unconfined compressive strength (q_u) relationship with the used hydrated lime content.

4.3 Compaction

The relationship between maximum dry density (MDD) and the used hydrated lime content, in addition to the optimum moisture content (OMC) relationship with the used hydrated lime content can be seen in Figure 6 and Figure 7 respectively. The best trend line for the MDD versus HL plot is the linear correlation with a high coefficient of determination R^2 equal to 0.9792 as shown in Figure 6 and the obtained corresponding linear equation as follows:

MDD ($gm.cm^{-3}$) = 0.0201 HL + 1.5728 (5)

The linear trend line for the OMC versus HL plot gave a high coefficient of determination ($R^2 = 0.9854$) as shown in Figure 7 and the obtained corresponding linear equation as follows;

OMC (%) = -1.01 HL + 27.604 (6)

[CHART]

Figure 6: Maximum dry density (MDD) relationship with the used hydrated lime content.

[CHART]

Figure 7: Optimum moisture content (OMC) relationship with the used hydrated lime content.

5. Conclusion

On the basis of the test results, the following conclusions can be drawn:

- The CL soil's Liquid limit and plasticity index decrease substantially, whereas plastic limit increases with hydrated lime content increase.
- The CL soil's maximum dry density is found to be increased, while the optimum water content is found to be decreased with an increase in the hydrated lime content.
- A significant increase of the CL soil's unconfined compressive strength value was found with an increase in hydrated lime content, the increase peak point was found at the optimum hydrated lime content.
- The obtained coefficient of determination, R^2, for the established relationships between the CL soil geotechnical characteristics and the used hydrated lime content, indicate that these expressions are suitable for the determination of the compaction and strength characteristics for CL soil treated with various percentages of hydrated lime.

List of Symbols

Symbol Description

ASTM American Society for Testing and Materials

LL Liquid Limit

PL Plastic Limit

PI Plasticity Index

HL Hydrated Lime

MDD Maximum Dry Density

OMC Optimum Moisture Content

R^2 Coefficient of Determination

UCS Unconfined Compressive Strength

UCSC Unified Soil Classification System

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Conflict of Interest

Authors have no conflict of interest relevant to this article.

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