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The Unconfined Compressive Strength of Hydrated Lime Stabilized Clayey Soil at Different Water Contents and Different Curing Times

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Abstract- **This research was done to find out how adding hydrated lime and extra water content to clayey soil samples affecting their unconfined compressive strength (UCS). The clayey soil is a locally available soil from the clayey soil area in Cyrene, northeastern of Libya. In the soil samples, hydrated lime (HL) was added at a rate of 5% of the dry weight of the soil. The standard compaction test was conducted on the untreated natural soil sample “NS” so that the optimum water content at the maximum dry density can be determined w_{op1}. Because of the addition of hydrated lime to the soil will affect the dry density-water content relationship, the standard compaction test was conducted again on the treated soil sample “NS+5%HL” to determine another optimum water content w_{op2}. These optimum water values {w_{op1} =17.8 & w_{op2}=19.5} will be used to prepare unconfined compressive strength specimens. In the experimental work two soil mixtures will be used beside the natural soil mixture. The first mixture "NS+5%HL+w_{op1}" and the second mixture "NS+5%HL+w_{op2}" were prepared in addition to the natural soil mixture "NS+w_{op1}". All unconfined compressive strength specimens for the first and second mixtures were extracted and tested at 7 and 14 days of curing, then comparison were made. The first mixture, "NS+5%HL+w_{op1}" will be compared with the natural soil mixture, "NS+ w_{op1}" in order to understand the impact of HL addition. The effect of the water content changing can be seen when the second mixture, "NS+5%HL+w_{op2}" is compared with the first mixture, NS+5%HL+w_{op1}. According to the findings, Although the first mixture’s specimens have the least dry density value, the UCS values increased by 218.5 and 386.5% at 7 and 14 days of curing, respectively, when compared to the natural soil mixture. This illustrates the result of the added hydrated lime. At curing times of 7 and 14 days, respectively, the UCS values for the second mixture fell by 8.61 and 14.11% when compared to the first mixture. And this illustrates the impact of variations in water content.**

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Index Terms: **Clayey soil, hydrated lime, optimum water content, unconfined compressive strength.**

I. INTRODUCTION

Many types of soils are employed in civil engineering projects; however, although some soil deposits are appropriate for construction in their natural state, others, such clayey soils, are not employed without stabilization.

Before they can support the applied loads by the top structures, these soils must either be replaced or their characteristics must be stabilized. [1]

Several geotechnical techniques are used to change and improve the state of unsuitable ground in situations when soil replacement is either not feasible or not cost-effective. [2]

Stabilization techniques designed to maintain stability, improve engineering qualities, reduce the capacity for water absorption, and decrease the compressibility of the treated soil [2].

There are several types of soils in the world, and they can be differentiated according to their particle size and consistency boundaries [3]. Expansive soil, active clay, and problematic soil are other names for clayey soil [4]. This particular form of soil is particularly sensitive to any alteration in its water content. Such Soils respond to changes in their moisture content with a noticeable volumetric change, which negatively impacts the over-lied building [3].

Because of the existence of expandable minerals, this volume change happens. These minerals like to absorb water into their layers, which causes them to swell or expand [4]. Clayey soils need to be stabilized since they have a propensity to fluctuate their volume significantly, which could cause engineering works to become severely stressed before being destroyed [5].

In arid or semi-arid regions all throughout the world, clayey soils can be found. They contain minerals from the Montmorillonite, Kaolinite, and Illite families [6]. The Montmorillonite mineral group is distinguished by its extremely high Cation Exchange Capacity, very small particle size, and large surface area. [7]

More money is lost each year due to clayey soil damage. This damage is more than the damage caused by floods, hurricanes, tornadoes, and earthquakes combined. However, due to the high cost of earthworks, haulage, and the decreasing availability of spoil regions as a result of the developed environment, the cost of cutting clayey soils to spoil during construction projects has continued to increase [2]

The average annual cost of damage to structures from shrinking and swelling of clayey soil is estimated to be 400 million pounds in the UK, 15 billion dollars in the US, and many billions of dollars globally [8].

The most popular calcium-based chemical binders are lime and cement, which, through pozzolanic and hydration processes, can reduce the soil's expansive power [9].

The process by which calcium-rich stabilizers modify clay involves the breakdown of calcium content into calcium ions, which then interact with silica and alumina leading to ion exchange, flocculation, and pozzolanic reactions. Equations (1 to 3) express this process. [10]

$$C_a(OH)_2 \rightarrow C_a^{+2} + 2(OH)^- \text{ ......(1)}$$

$$C_a^{+2} + 2(OH)^- + S_iO_2 \rightarrow CSH \text{ ......(2)}$$

$$C_a^{+2} + 2(OH)^- + AlO_2 \rightarrow CAH \text{ ......(3)}$$

When the pozzolanic reaction take place, Silica and alumina in the clay sheets combine with calcium resulting in cementitious materials such as Calcium Silicate Hydrates (CSH) and Calcium Aluminate Hydrates (CAH). These cementitious components are to blame for the clay soil's enhanced mechanical characteristics and decreased expansivity [10].

Besides, the OH^- ions present in calcium hydroxide increases the pH of the soil. This environment makes the aluminosilicates dissolve gradually and contributes to the long term strength gain [10].

The aim of this work is to study the effect of hydrated lime addition and water content change on the unconfined compressive strength of the clay soil at the curing time of 7 and 14 days.

II. MATERIALS AND METHODOLOGY

A. Soil

The soils used in this study were a sample of naturally expanding soil from the Cyrene region in northeastern Libya. The region is located at 32.8226595° N and 21.8700631° E and is between 600 and 650 meters above sea level.

The expanding soil was collected between 0.6 and 1.5 meters below the surface of the land. According to USCS, (Unified Soil Classification System) the soil was categorized as CL (Clay with Low Plasticity).

Additionally, it was categorized as A-6 (clayey soil) by the American Association of State Highway and Transportation Officials (AASHTO).

Figure. 1 presents the clayey soil's grain size distribution. The mean particle size and particle size distribution were calculated using the hydrometer test.

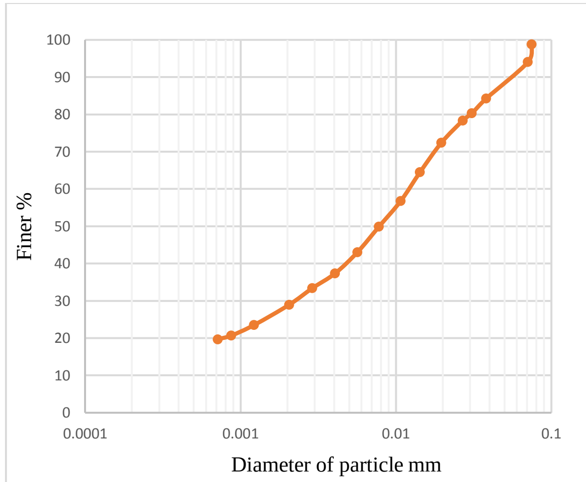

Figure. 1: The particle size distribution of the clayey soil

Soils were dried at 105C°, then ground with a grinder, and stored in plastic bags to prevent deterioration from humidity.

The primary physical characteristics of the natural clayey soil employed in this experiment are displayed in Table 1.

Table 1: Physical properties of the clayey soil and the standard used.

Properties	**Clayey Soil**	**Standard**
Gravel (%)	0	
Sand (%)	1.2	ASTM D422
Silt (%)	70.8	ASTM D422
Clay (%)	28	ASTM D422
Liquid Limit (%)	36.9	ASTM D4318
Plastic Limit (%)	18.54	ASTM D4318
Plasticity index (%)	18.36	_
Shrinkage Limit (%)	17.48	ASTM D427
Specific Gravity	2.69	ASTM D2216
Optimum Moisture Content (%)	17.8	ASTM D698
Maximum Dry Density (g/cc)	1.75	ASTM D698
Free Swell Index (%)	8.3	IS 2720
Unconfined Compressive Strength (Kpa)	354	ASTM D2166

With the exception of the free swell index, which was reached using the Indian Standard, all investigations were carried out in compliance with ASTM (American Society for Testing and Materials).

B. Additive

Hydrated lime, or Calcium Hydroxide {Ca(OH)2}, is the addition that was examined in this study. Commercial lime was the stabilizer, and it was sold in the local markets.

The chemistry of this additive, as determined in a previous study by X-ray fluorescence (XRF), is shown in Table 2.

Table 2: Chemical composition of hydrated lime [11]

Oxides	**Hydrated Lime %**
C_aO	86
M_gO	4
S_iO_2	1.5
Al_2O_3	0.1
Fe_2O_3	0.1
M_nO	0.1
$N_{a2}O$	0.1
K_2O	0.1
T_iO_2	0.1
P_2O_5	0.1
Lol (loss of ignition, 950C°)	29.1

In order to facilitate the hydrated lime's hydration and interaction with the soil, the maximum particle size of the HL was set at 2 mm.

III. PREPARATION OF TREATED SOIL

The samples were made by combining natural soil with 5% hydrated lime (HL) (by total dry weight of the natural soil) (NS). After that, distilled water was added using a quantity of water corresponding to the optimum water content.

The experimental effort identified two optimum water contents, designated as w_{op1} and w_{op2}. The results of the standard compaction test on the natural soil were used to estimate the first optimum water content, or w_{op1}.

The standard compaction test performed on the clayey soil treated with 5% hydrated lime allowed for the determination of the second optimum water content, or w_{op2}.

As a result, two mixtures, NS+5%HL+w_{op1} and NS+5%HL+w_{op2}, were used in this study in addition to the natural soil mixture NS+w_{op1}. The testing process is schematically represented in Figure 2.

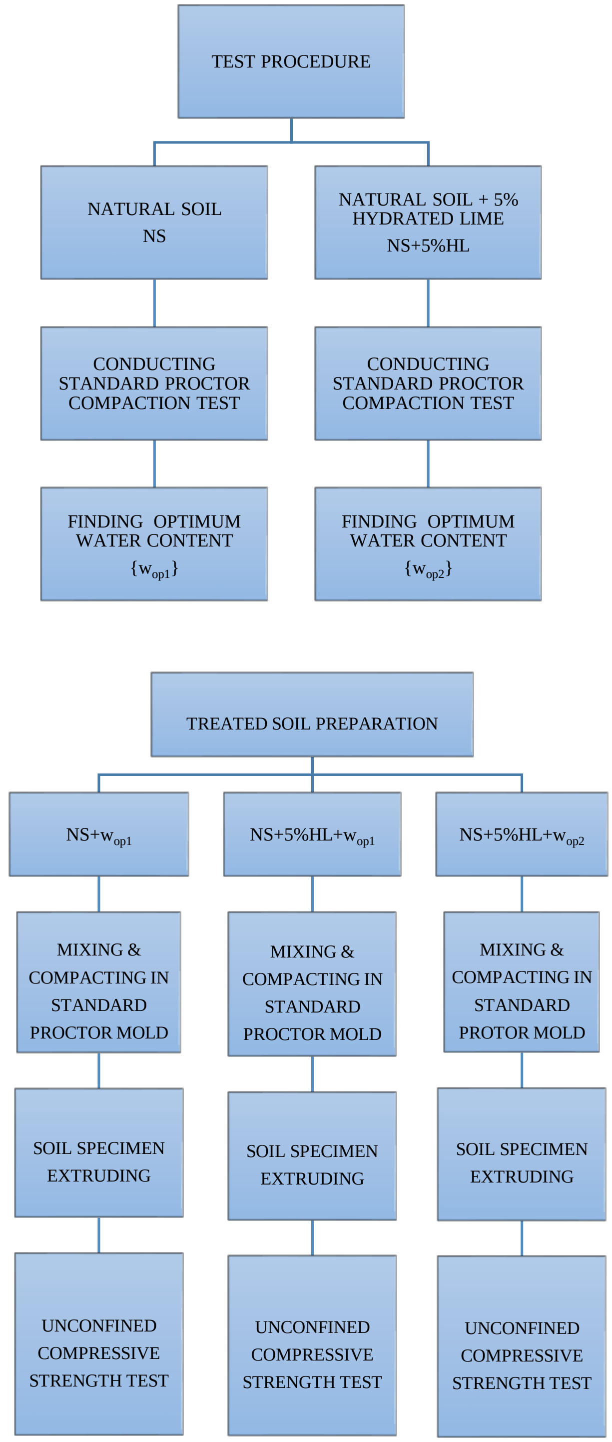

Figure 2: Schematic representation of the testing procedure.

Specimen of unconfined compressive strength UCS for all mixtures were prepared at the maximum dry density and tested at curing time of 7 and 14 days and comparison were made. The samples were prepared and wrapped "in double cellophane" before being put into a desiccator for curing.

IV. RESULTS AND DISCUTION

A number of lab tests involving compaction and unconfined compressive strength test were carried out. They were carried out in line with ASTM standards (American Society for Testing and Materials).

A. Effect on the Compactability

The compaction curves for NS and NS+5%HL are shown in Figure. 3. The addition of 5%HL to the soil raised the optimum water content w_{op} while decreasing the maximum dry density MDD, as seen in Table 3 and Figure. 3.

Table 3: Compaction results for NS and NS+5%HL.

Mixture	Maximum Dry Density MDD g/cc	Optimum Water Content w_{op} %
NS	1.75	w_{op1}=17.8
NS+5%HL	1.65	w_{op2}=19.5

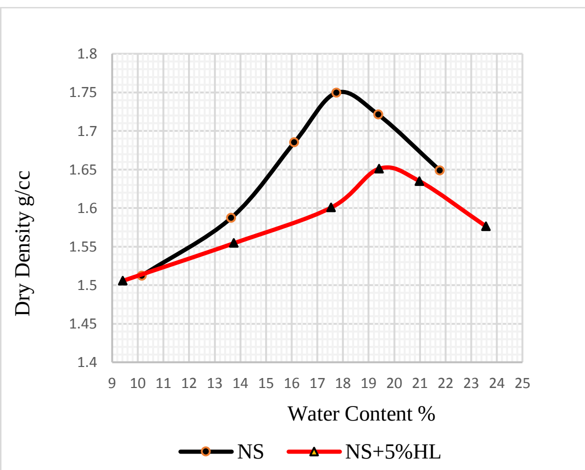

Figure. 3. Compaction curves for NS and NS+5%HL.

The decrease in maximum dry density could be attributed to three factors. One of these is that the flocculated and agglomerated clay particles (produced by the cation exchange reaction) now occupy bigger spaces, increasing the volume of the voids and ultimately decreasing the mass: volume ratio. The other involves substituting hydrated lime particles with a relatively lower specific gravity for soil particles in a given volume [12].

In addition, soil particles may form connections with hydrated lime that firmly bind the particles together and withstand the compaction effort. [13]

The rising demand for water is assumed to be the cause of the growing ideal moisture content. Where the calcium hydroxide must dissolve in more water in order to separate into C_a^{2+} and OH ions. This product, calcium hydroxide, dissolves to release more C_a^{2+} ions for the cation exchange reaction. [12]

B. Effect on the Unconfined Compression Strength

The stability of clayey soil as a result of hydrated lime addition and changes in water content is shown in Figure. 4 and Table.4.

The UCS values increased from 354 Kpa for the natural soil to 1127 and 1722 Kpa at 7 and 14 days, respectively, when 5% hydrated lime was introduced to the clayey soil. And these adjustments to the UCS values reflect the impact of the addition of hydrated lime.

It is also investigated how variations in water content affect UCS values. The values of UCS fell to 1030 and 1479 Kpa at 7 and 14 days, respectively, when the water content for the first mixture, NS+5%HL+w_{op1}, varied from 17.8 to 19.5%.

Table 4: Values of dry density and Unconfined Compression Strength for soil mixtures specimens

Mixture	Dry Density g/cc	Unconfined Compressive Strength Kpa	
		At 7d	At 14d
NS+ w_{op1}	1.75	354	
NS+5%HL+ w_{op1}	1.60	1127	1722
NS+5%HL+ w_{op2}	1.65	1030	1479

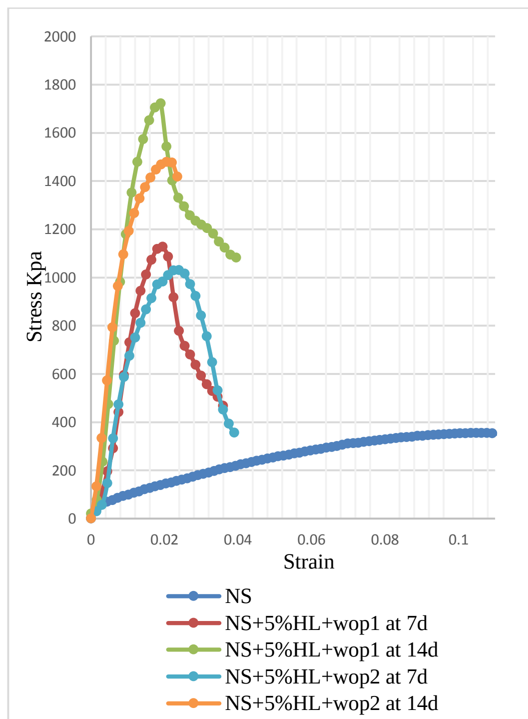

Figure. 4: stress- strain curves for natural and treated clayey soils

The stability of clayey soil as a result of hydrated lime addition can be attributed to the pozzolanic reactions. In these pozzolanic reactions, the Silica and alumina in the clay sheets combine with calcium resulting in cementitious materials such as Calcium Silicate Hydrates and Calcium Aluminate Hydrates. These cementitious components are to blame for the clay soil's enhanced mechanical characteristics and decreased expansivity.

Although the specimen from the second mixture has a higher dry density (1.65 g/cc) than the specimen from the first mixture (1.6 g/cc), the UCS values were lower. And this is may be explained by the higher void ratio that cementing chemicals may fill.

V. CONCLUSION

This study has evaluated the extent to which hydrated lime and water content changes can change the mechanical properties of clayey soil.

The results have shown that hydrated lime reduces the maximum dry density and increases the strength of clayey soil. This increase in strength is still continued beyond 14 days.

The highest strength and stiffness achieved at 7 and 14 days was correspond to the hydrated lime-treated clayey soil containing low water content {w_{op1}=17.8%}.

When this water content increased to 19.5% there was a reduction in the strength of clayey soil at both curing times 7 and 14 days. According to general relationship between UCS and consistency Table 5, the consistency of all treated clayey soil in this study changed from very stiff to hard.

Table 5: The Relationship between Unconfined Compressive Strength UCS and Consistency [7]

Consistency	Unconfined Compressive Strength Kpa
Very soft	0-25
Soft	25-50
Medium	50-100
Stiff	100-200
Very stiff	200-400
Hard	>400

REFERENCES

[1] Ikeagwuani, C. C., & Nwonu, D. C. (2019). Emerging trends in expansive soil stabilization: A review. Journal of rock mechanics and geotechnical engineering, 11(2), 423-440.

[2] Fondjo, A. A., Theron, E., & Ray, R. P. (2021). Stabilization of expansive soils using mechanical and chemical meth-ods: a comprehensive review. Civ Eng Archit, 9, 1295-308.

[3] A Alghrubah, A., A Abd Elrahman, M., F Abd Rabbo, M., A Al-Mashad, Y., G Salama, A., H Mahmoud, B., & A Dawood, W. (2021). The effect of Lubricant Oils on the Swelling Behavior of Loam. Engineering Research Journal-Faculty of Engineering (Shoubra), 50(1), 86-92.

[4] Zamin, B., Nasir, H., Farooq, A., Jehan, B., & Bashir, M. T. Effect of Waste Glass Powder on the Swelling and Strength Characteristic of Karak Expansive Clay.

[5] Zeini, H. A., & Alabdaly, N. M. (2020). Improving Expansive Soil Properties by Adding Fuel Oil. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, 70(1), 136-143.

[6] Devkota, B., Karim, M. R., Rahman, M. M., & Nguyen, H. B. K. (2022). Accounting for Expansive Soil Movement in Geotechnical Design—A State-of-the-Art Review. Sustainability, 14(23), 15662.

[7] Das, B. M. (Ed.). (2010). Geotechnical engineering hand-book. J. Ross publishing.

[8] Hussein, S. A., & Ali, H. A. (2019). Stabilization of expansive soils using polypropylene fiber. Civil Engineering Journal, 5(3), 624-635.

[9] Mazhar, S., & GuhaRay, A. (2021). Stabilization of expansive clay by fiber reinforced alkali-activated binder: an experimental investigation and prediction modelling. International Journal of Geotechnical Engineering, 15(8), 977-993.

[10] Jalal, F. E., Xu, Y., Jamhiri, B., & Memon, S. A. (2020). On the recent trends in expansive soil stabilization using calcium-based stabilizer materials (CSMs): a comprehensive re-view. Advances in Materials Science and Engineering, 2020, 1-23.

[11] Sol-Sánchez, M., Castro, J., Ureña, C., & Azañón, J. M. (2016). Stabilization of clayey and marly soils using industrial wastes: pH and laser granulometry indicators. Engineering geology, 200, 10-17.

[12] Asad, A., Hussain, A., Farhan, A., Bhatti, A. A., & Munir, M. (2019). Influence of lime on low plastic clay soil used as subgrade. Journal of Mechanics of Continua and Mathematical Sciences, 14(1), 69-77.

[13] Abdalla, T. A., & Salih, N. B. (2020). Hydrated lime effects on geotechnical properties of clayey soil. Journal of Engineering, 26(11), 150-169.