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Chemical Effect on Soil Strength by adding Lime and Natural Pozzolana

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Abstract

Mostly, clay soil is a common problem encountered by civil engineers on site, because of its complicated structure and different geotechnical properties. Therefore, it was necessary to find useful and applicable solutions to solve problems that may be found upon designing and constructing. One of the most widespread solutions for soil improvement is soil stabilization by different types of additives, which achieves high efficiency and economical results. Many additives were used, including cement, lime, silica, fly ash, and others. A lot of natural resources of lime and pozzolana exist in Syria, however, it needs investment plans, and due to the lack of studies that discuss using these additives under foundations and then detecting the changing of bearing capacity of the soil. In this research, experimental and analytical methods are followed by conducting loading experiments on a foundation model located on clay soil, after adding lime to clay soil with percentage 2% up to 8%, which cause a decrease in the water content and increases the strength of soil where the maximum was at 4% lime. Then 10% up to 30% of natural pozzolana were added alongside 4% of lime, which caused decreasing in both the water content and the strength.

Keywords: *Lime, Pozzolana, Additive, Soil improvement.*

1. Introduction

The soil under different construction, such as roads, residential and industrial buildings, irrigation facilities, and airports; may not satisfy the engineering requirements. So, engineers always try to modify the engineering design such as: increasing the thickness of the pavement layers or increasing the dimensions of the footing, or changing the type of footing from shallow to deep, and this causes a significant increase in the cost of the structure as a whole. Recently, engineers and researchers concentrate on finding new methods to improve the soil properties and approaching the standards values which minimize the cost of any other modifying. Therefore, soil stabilization science and its applications have attractive research and studies. It provides economic solutions for many soil problems. There are the main group of improving methods: mechanical methods (soil reinforcement and soil mixing), and chemical (soil injection with chemical additives: cement, lime, fly ash, silicates, and polymers). Using lime and natural pozzolana as additives were main concept for many types of research since natural pozzolans used in normal proportions typically improve concrete performance and durability [Ekolu, et al., 2006], however, a few of research investigates the changing of soil properties by using both lime and pozzolana under loads. Moreover, the availability of natural lime and pozzolana in Syria encourages searching and detecting the effect of these additives on soil under foundations.

[Tran, et al., 2014] investigated the effects of lime treatment on the microstructure and hydraulic conductivity of compacted expansive clays that result in increasing hydraulic conductivity in lime-treated soil. [Abbasi & Mahdieh, 2018] studied Adding lime or pozzolan or both of them to a silty sand soil causes an increase in optimum moisture content and a decrease in the maximum dry density.

[Khan, et al., 2020] studied different types of stabilizers to improve the strength of soil, and [Harichane, et al., 2011] and [Harichane, et al., 2017] studied adding lime (0-4-8)% and pozzolana (0-10-20)% on two types of clay soils, they found that pozzolana enhances the effect of lime on decreasing the plasticity index the classification of soil change from CH to MH for both types. [Haas & Ritter, 2018] clarified in their research the effect of time on the degree of reaction of quicklime and hence the increase of compressive strength. [Alrubaye, et al., 2016] studied kaolin clay and mixed (3-5-7-9)% lime and 4% silica dust. the result was a decrease in the maximum density and an increase in shear strength and internal friction angle. [Türköz, et al., 2018] concentrated on silica dust (1-3-5-10-15-20) % and lime (3%) and found decreasing in the plasticity Index of a clay soil from Turkey and an increase in maximum dry density. [Kalyane & Patil, 2020] tried to stabilize black cotton soil from India by using lime (5%) and fly ash (5-10-15)%, which reach to increasing plasticity limit and unconfined strength and decreasing in maximum dry density. Many types of research expressed the increasing of bearing capacity with a module (BCR) bearing capacity ratio which expresses the proportion between bearing capacity after improvement and virgin bearing capacity (before improvement or stabilization). All researchers used a laboratory model to define this ratio. [Maharaj, et al., 2019] studied the bearing capacity ratio of soil after reinforcement with geotextile, and concluded that the maximal increase in ultimate bearing capacity is ascertained by placing the reinforcement at a depth of half the width of footing (B). [Keskin & Laman, 2012] investigated the bearing capacity of a strip footing resting on sand slopes, and found that the bearing capacity of strip footing on a sand slope is significantly

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dependent on the slope angle, and increases with an increase in the relative density of sand. In other research, [Gabr, et al. 1998] studied the stress distribution for reinforcement soil under square footing (0.33m*0.33m) loaded in a metal box (1.37m*1.52m*1.52m). [Tsukada, et al., 2006] used circle footing with a diameter (of 40mm) on reinforcement soil and studied BCR for spread footing. [Hwang, et al., 2016] researched the effect of Micropile on increasing the bearing capacity of the soil. Therefore, the goal of this research was to study the effect of lime and natural pozzolana on soil strength. The research was done experimentally in a physical laboratory model.

2. Materials & Methods:

2.1 Materials:

The soil in the area of Dara'a (locating in the south of Syria) causes many problems under foundations for different types of buildings where most researchers suggested that the reason is due to its high plasticity. Therefore, according to the previous papers and research, this paper focuses on detecting the changing in the soil properties after adding two types of available additives lime and natural pozzolana in Syria. Limestone quarry spread in different locations in Syria and the expected geological reserve is $8*10^9$ m³, just the investment quantity is approximately $200*10^6$ m³ [General Establishment]. In addition, Pozzolana spreads in the south area, east-south area, and east-north area in Syria, the expected geological reserve is $600*10^6$ m³ [14].

2.2 Methods:

2.2.1 Soil Samples Tests:

Basically, all soil samples have been tested in the soil mechanics laboratory to be classified and specified. Fig.1 illustrates the grain size distribution of soil samples according to ASTM D6913 and D7928. Fig. 2 presents the proctor tests results to define the maximum dry density according to ASTM D698, and fig.3 shows the unconfined compressive strength (UCS) results for these types of samples. In addition, Atterberg limits have been determined as clarified in Table 1.

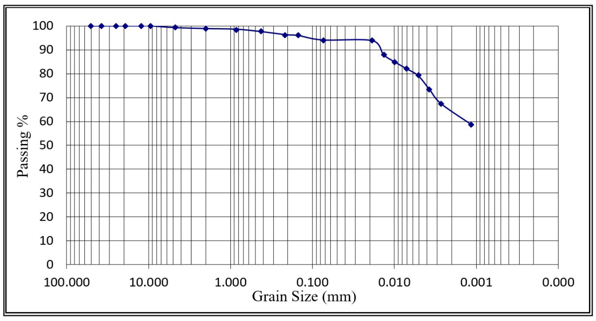

Figure 1. Grain Distribution.

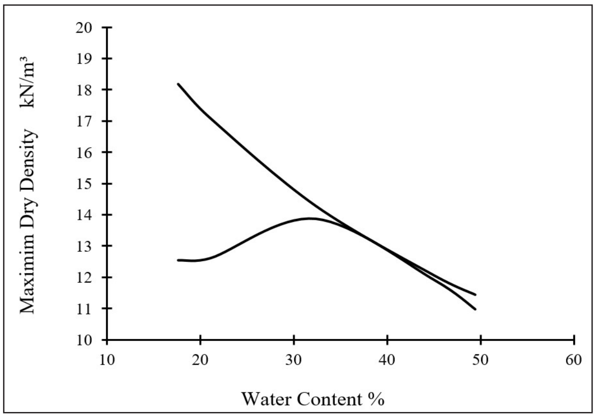

Figure 2. Compaction Test.

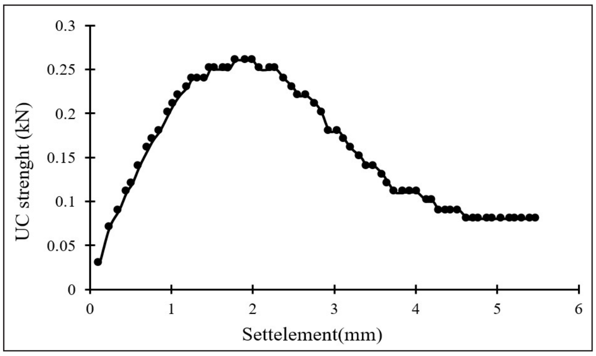

Figure 3. Unconfined Compressive Strength.

Table 1. Physical properties of clay soil

Test	ASTM code	Result
Moisture (water content)	D 2216	10%
Specific Gravity (Gs)	D 854	2.753
Grain Size Distribution: Sieve Hydrometer	 D 6913 D 7928	Gravel (0.73) %, Sand (5.17)%, Silt (29.50)%, Clay (64.60)%
Atterberg Limits	D 4318	LL=74.09%, PL=38.10%, Class - CH
Compaction Test	D 698	Fig.2
Unconfined Compressive Strength	D 2166	Fig.3

2.2.2 Additive Tests:

Then, both additive lime and natural pozzaolana have testes chemically. The lime additive contains 90.2% (CaO). Blaine fineness test according to (ASM-C204) shows fineness (4500±100) cm²/gr of natural pozzolana that was used in this research. Syrian standards (1998/1887) recommend that active silica should not be less than 25% in pozzolana to assure the activity of pozzolana as an additive. Chemical analysis for pozzolana is as follows in table2:

Table 2. Chemical Analysis of Pozzolana.

Oxide	SO_3	K_2O	MgO	CaO	Fe_2O_3	Al_2O_3	SiO_2 (active)	SiO_2 (all)
%	0.32	7.47	8.02	8.29	16.04	12.57	44.31	47.29

2.2.3 Laboratory Model:

The laboratory model is a plexiglass box with dimensions (30cm*35cm*50cm). It was filled with soil and the model of footing is a metal plate, its dimensions: (30cm*8cm). The settlement gauge was placed at the top of the plate as shown in fig. 4. The loading device was a hydraulic press with a velocity of 0.5mm/sec and the maximum settlement was calculated as 20% of the footing width (for our case = 16mm) [Das, 2011].

Figure 4. Laboratory Model.

2.2.4 Laboratory Methodology:

- Prepare the laboratory model.
- Adding lime with a percentage **of 2%-4%-6%-8%** then find the best additive percentage of lime.
- Adding Pozzolana with percentages **10%-20%-30%** with the optimum percentage of lime and applying load tests until failure.
- Choose the best mixing percentage.

2.2.5 Loading Test Procedures:

The samples were disturbed, so an approximate unit weight and water content were determined: γ=15kN/m^3, w=40%. Big Samples were crushed and then water was added to the soil sample and kept it 24 hours. Then, quick lime was crushed and sieved on sieve No. 40. When samples get their water content, the lime, and pozzolana are added to the sample and mixed for not less than half an hour until reached homogenous, then forming the soil layers inside the box and leaving the soil for 24 hours to be as homogenous as much, and then begin with loading steps. After finalizing the loading, the box is emptied, and repeat the steps to do a new experiment are. In each experiment, 80kg of soil was used, and 22kg of water to reach the required water content, in addition to lime and pozzolana after grinding. The loading process could be divided into three main stages:

1) Virgin soil without any additions:

After the loading test the maximum load for settlement 20% of footing width, was Q=4.8kN.

2) Soil with Lime:

Lime was added to the soil with percentages (of 2%, 4%, 6%, and 8%). Fig. 5 shows the results of loading where the maximum load for 2% lime additive was 8.45kN, for 4% lime additive was 13.5kN, for 6% lime additive was 12.4kN and for 8% lime additive was 11kN.

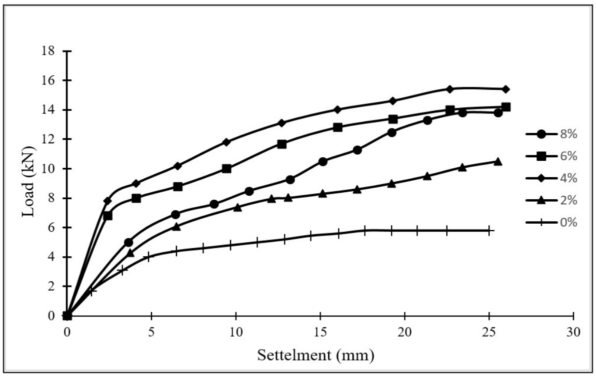

Figure 5. Loading Test Curves for stabilized samples with lime additives.

To study the effect of lime additives, it is obvious that maximum load increase by increasing lime additives until 4% then begin to decrease as shown in fig. 6.

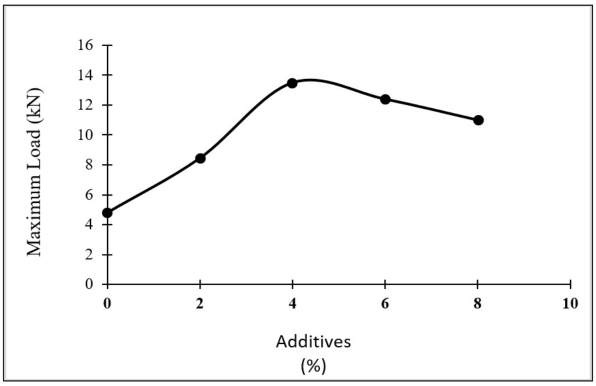

Figure 6. Maximum Load vs Lime additive percentages.

Moreover, fig. illustrates the relation between water content and lime additives. Lime additives cause decreasing in water content.

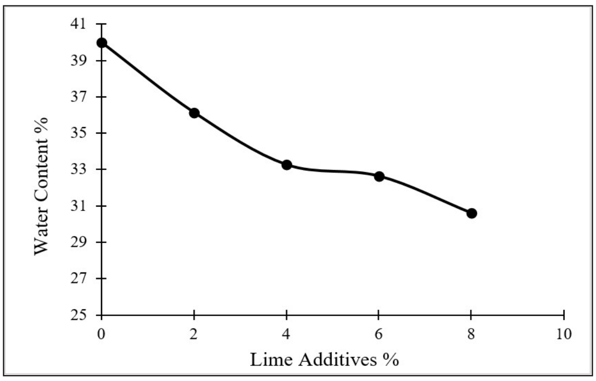

Figure 7. Water Content vs additive percentages.

Fig. 8 shows the results of the unconfined compressive strength (UCS) test and it is clear that the best additive ratio is 4%, which increases the strength of the sample significantly. It is the same trend in fig. 9, which presents the stress-strain behavior.

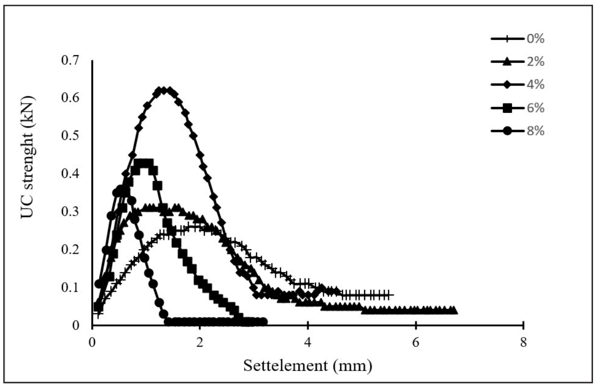

Figure 8. Unconfined Compression Strength.

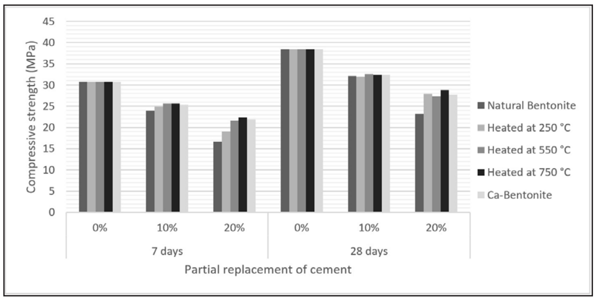

Figure 9. Stress-Strain Curves.

2) Soil with Lime & Pozzolana:

After we define the optimum ratio for lime additive as 4%, we fixed this ratio and begin to add pozzolana with a percentage of 10%-20%-30% to explore the effect of lime and pozzolana together in changing the soil properties. Fig. 10 shows the loading results and Fig.11 shows the effect of pozzolana additives on the water content in a soil sample. Moreover, Fig. 12 shows the results of the UCS test where adding pozzolana caused decreasing in UCS compared with a mixture of soil and lime only. We notice the same trend in Fig. 13, which present the stress-strain behavior.

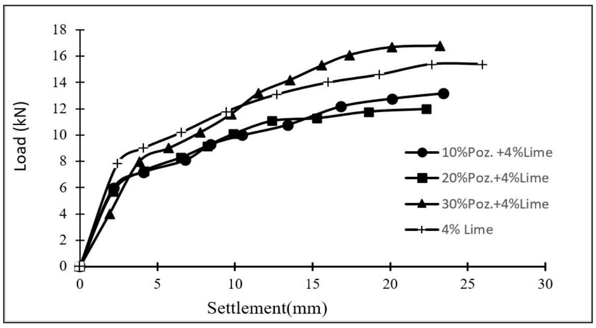

Figure 10. Loading Test Curves.

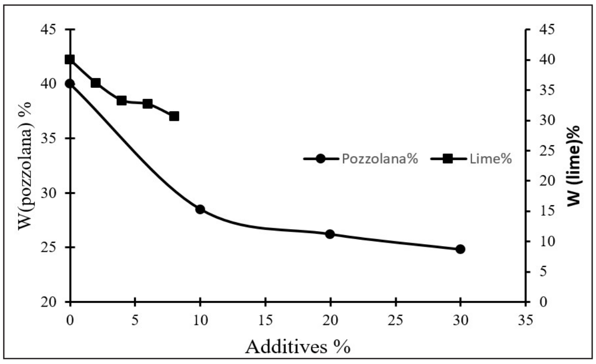

Figure 11. Water Content vs. Additives Percentages.

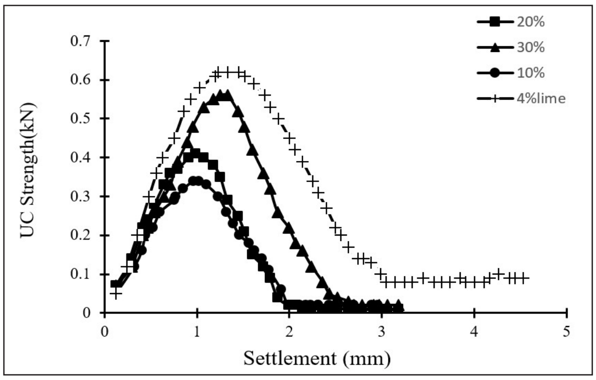

Figure 12. Unconfined Compression Strength.

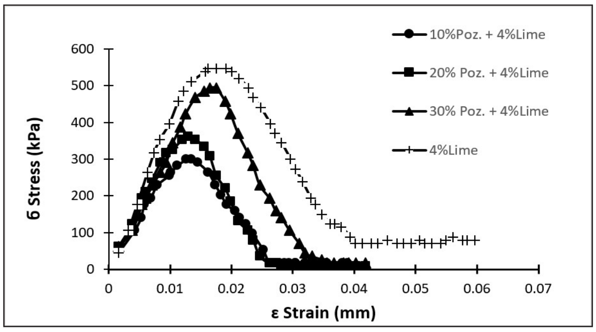

Figure 13. Stress–Strain Curves.

3. Discussion:

According to the results as shown in Fig. 8, we notice that UCS tests for soil samples after mixing with different ratios of lime match the load test results (Fig.5) and together give that the best ratio of additives is 4%. Moreover, Fig.9 presents, at the same strain percentage that the maximum value of stress increase from 220kPa up to 546kPa when the lime additive is 0% and 4% respectively, which confirms the great effect of lime on increasing the strength of the soil. Upon using natural pozzolana it is obvious from Fig.10 to Fig. 13 a decrease in the strength of soil samples compared to the strength value for soil samples without pozzolana and with lime additives only. Table 3 clarifies the differences in maximum loads according to pozzolana percentages. pozzolana may replace soil particles and works with lime to improve the soil in case the pozzolana additive percentage is more than 30%. We could explain this by the lime reaction.

Table 3. Maximum loads after adding Pozzolana

Maximum Load (kN)	Soil with Additives
4.8	Virgin Soil
13.5	Soil+4% Lime
11.7	Soil+4% Lime+10%Pozzolana
11.8	Soil+4% Lime+20%Pozzolana
14.3	Soil+4% Lime+30%Pozzolana

3.1 Lime reaction:

Calcium Oxide reacts with existing water in the voids of soil and release heat during and after the reaction so the water content of the soil decreases as shown in Fig. 11. The reaction occurs according to the following equation:

$$CaO + H_2O \rightarrow Ca(OH)_2 + Heat$$

The previous reaction could continue for many years and create a chemical bond between soil particles as cement bonds that result from cement hydration. Calcium additives increase soil pH, which causes dissolution of soil components (silicates and alumina), after the dissolution, silicates, and alumina react with calcium and result hydrate calcium alumina CAH and hydrate calcium silicate CSH according to following equations:

$$2\ Ca_3SiO_5 + 7\ H_2O \rightarrow 3\ CaO \cdot 2\ SiO_2 \cdot 4\ H_2O + 3\ Ca(OH)_2 + 173.6\ kJ$$

$$8Ca^{++} + 16(OH) + Al_2O_3 \rightarrow 8CaO \cdot Al_2O_3 \cdot 8\ H2O$$

The compounds that result from the previous equation are hard crystal materials and do not dissolve in water so it provides soil with strength. A practical consequence of the pozzolanic reaction is the gradual hardening of pastes containing pozzolanic materials and lime. Strength increases as the number of combined lime increases. However, may be pozzolana responsible for low early strength, and as much as pozzolana quantity increases as much as strength increases [McCarthy & Dyer, 2019].

4. Conclusion:

Results could be summarized as follows:

- Lime affects decreasing the water content and this effect increases directly with the percentage of lime. On the other hand, the water content decreases by approximately 25% of its initial value at the highest ratio of additives e.g. lime 8%.
- Lime additive increases UCS of soil and there is always an optimum ratio of additives, in our case, it was 4%.
- Lime additives enhance the bearing of soil by increasing the maximum load of soil. In our research, the maximum load increase is 2.8 fold from the initial one.
- Pozzolana additives enhance decreasing water content.
- Pozzolana decreases the strength compared with the effect of lime additives alone.
- The best percentage of Pozzolana additives is 30% for our soil samples.
- Moreover, it could be recommended to:
- Studying pozzolana additives ratio greater than 30% along with 4% of lime additives.
- Studying pozzolana additives with a lime ratio greater than 4%.
- Studying the effect of pozzolana fineness on strength of soil with pozzolana and lime.

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Conflicts of Interest:

"The authors declare no conflict of interest."

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