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Effect of curing time on shear strength of cohesive soils stabilized with combination of lime and natural pozzolana

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Abstract

When geotechnical engineers are faced with cohesive clayey soils, the engineering properties of those soils may need to be improved to make them suitable for construction. The aim of this paper is to study the effect of using lime, natural pozzolana or a combination of both on the geotechnical characteristics of two cohesive soils. Lime or natural pozzolana were added to these soils at ranges of 0-8% and 0-20%, respectively. In addition, combinations of lime-natural pozzolana were added at the same ranges. Test specimens were subjected to compaction tests and shear tests. Specimens were cured for 1, 7, 28 and 90 days after which they were tested for shear strength tests. Based on the experimental results, it was concluded that the combination lime-natural pozzolana showed an appreciable improvement of the cohesion and internal friction angle with curing period and particularly at later ages for both soils.

Keywords: Cohesive soil, Lime, Natural pozzolana, Compaction, Shear strength, Curing

1. Introduction

Civil engineering projects located in areas with unsuitable soils is one of the most common problems in many parts of the world. The old usual method to soil stabilization is to remove the unsuitable soil and replace it with a stronger material. The high cost of this method has driven researchers to look for alternative methods and one of these methods is the process of soil stabilization.

Soil stabilization is a technique introduced many years ago with the main purpose to render the soils capable of meeting the requirements of the specific engineering projects [1]. In addition, when the soils at a site are poor or when they have an undesirable property making them unsuitable for use in a geotechnical projects, they may have to be stabilized [2]. In recent years, scientific techniques of soil stabilization have been introduced [3, 4].

Stabilized soil is, in general, a composite material that results from combination and optimization of properties in individual constituent materials [5]. The techniques of soil stabilization are often used to obtain geotechnical materials improved through the addition into soil of such cementing agents as cement, lime or industrial by-products as fly ash, slag, etc. Extensive studies have been carried out on the stabilization of soils using various additives such as lime and cement [6]. The combination of compaction method and cement stabilisation was also studied by some researchers as well as the stabilisation using natural fibres such as barley straw [7-9].

The potential for using industrial by-products for stabilization of clayey soils is promising. The use of these by-products and their combination with cement and lime have been used as soil stabilizers such as limestone [10], fly ash [1, 11-17], rice husk ash [5, 18-23], silica fume [24, 25] and cement kiln dust [26, 27].

Limited researches have been conducted to investigate the suitability of using natural pozzolana (NP) in soil stabilization. Hossain et al. [16] utilized volcanic ash (VA) from natural resources of Papua New Guinea. Several tests of compaction, unconfined compressive strength and durability were conducted, but the shear strength behaviour was not studied.

Natural pozzolana is found abundantly in extensive areas of Beni-Saf quarry in the West of Algeria [28]. The use of natural pozzolana and its combination with lime in conjunction with cohesive soils needs to be investigated. As the soil is good source of alumina, the effects of lime treatment can be enhanced to a great extent if the apparent shortage of silica can be adequately supplemented by the addition of natural pozzolana, which is high in reactive silica content. However,

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the literature indicates minimal studies on the stabilization of cohesive soils in Algeria.

This paper presents the results of the effect of curing time on shear strength of two Algerian cohesive soils, stabilized with combination of lime and natural pozzolana.

2. Experimental investigation

2.1Materials used

2.1.1. Soils

The first soil used in this study was obtained from an embankment project site and the second soil was obtained from a highway project site both near Chelif town in the West of Algeria. Previous soil investigations carried out at the site indicated the presence of unsuitable clays. These clays were encountered at a depth of about 4 to 5 m. The disturbed soil was excavated, placed in plastic bags, and transported to the laboratory for preparation and testing. Laboratory tests were carried out to classify each type of soil. The engineering properties of clayey soils are presented in table 1.

2.1.2. Natural pozzolana

The natural pozzolana (NP) used in this investigation was collected from Beni-Saf in the West of Algeria. The NP was ground in a laboratory mill to a specific surface area of 420 m^2/kg. The chemical composition of NP is presented in table 2.

2.1.3. Lime

The lime (L) used was a commercially available lime typically used for construction purposes. The chemical and physical properties of lime are presented in table 3.

2.2. Laboratory tests

A series of laboratory tests consisting of compaction and shear strength were conducted on the two selected clayey soils. Extensive combinations of natural pozzolana and lime were used for stabilization of the two soils. The percentages of NP were 0, 10, and 20%, while the percentages of the lime were 0, 4 and 8%. A total of 18 combinations based on soil 1 and soil 2 with single and mixed modes of stabilizers were studied (Table 4).

2.2.1. Compaction tests

Proctor standard compaction test according to ASTM D 698 [29] was applied to determine the maximum dry density (MDD) and the optimum moisture content (OMC) of the soils. The soil mixtures, with and without additives, were thoroughly mixed for 1 hour prior to compaction. The first series of compaction tests were aimed at determining the compaction properties of the unstabilized soils. Secondly, tests were

Table 1. Physical characteristics of the soils

Basic characteristics	Soil 1	Soil 2
Color	grey	red
Depth (m)	4m	5m
Natural water content (%)	32.87	13.77
Specific gravity	2.71	2.84
Passing 80 µm sieve (%)	85	97.5
Liquid limit (%)	84.8	47.79
Plastic limit (%)	32.78	23.23
Plasticity index (%)	52.02	24.56
Classification (USCS)	CH	CL
Optimum water content (%)	28.3	15.3
Maximum dry density (kN/m^3)	13.8	16.9
Unconfined compressive strength (kPa)	55.6	222.5

Table 2. Chemical composition of Natural Pozzolana

Chemical composition	Natural pozzolana (%)
SiO_2	46.4
Al_2O_3	17.5
Fe_2O_3	9.69
CaO	9.90
MgO	2.42
CaO free	-
SO_3	0.83
Na_2O	3.30
K_2O	1.51
TiO_2	2.10
P_2O_3	0.80
Loss of ignition	5.34

Table 3. Physical and chemical properties of lime

Chemical name	Lime
Physical appearance	Dry white powder
CaO	> 83.3
MgO	< 0.5
Fe_2O_3	< 2
Al_2O_3	< 1.5
SiO_2	< 2.5
SO_3	< 0.5
Na_2O	0.4 - 0.5
CO_2	< 5
$CaCO_3$	< 10
Specific gravity	2
Over 90 µm (%)	< 10
Over 630 µm (%)	0
Insoluble material (%)	< 1
Bulk density (g/l)	600-900

Table 4. Stabilizer combination scheme for stabilized soils

Designation	Sample mixture (%)		
	Soil	**NP**	**L**
P0L0	100	0	0
P0L4	96	0	4
P0L8	92	0	8
P10L0	90	10	0
P20L0	80	20	0
P10L4	86	10	4
P20L4	76	20	4
P10L8	82	10	8
P20L8	72	20	8

carried out to determine the proctor compaction properties of the clay upon stabilization with varying amounts of lime and natural pozzolana.

2.2.2. Shear strength tests

The direct shear tests were performed following ASTM D 6528 [30] and were conducted on treated and untreated samples compacted at maximum dry density and optimum moisture content. Since the specimens were not saturated, no excess pore water pressure would be expected in them. The direct shear test was unconsolidated and the load was applied at a rate of 1 mm/min. The normal stress was chosen 50, 100 and 200 kPa for all the specimens. Six specimens were prepared from each mixture and for each curing period. In order to avoid excessive moisture loss the specimens were wrapped up with a polyane film after demoulding. The specimens were kept in the laboratory at a temperature of 25°C and a relative humidity of 50%, until the test times (1, 7, 28 and 90 days).

3. Results and discussion

3.1. Compaction characteristics

The compaction test was used to determine the effect of stabilizers on maximum dry density (MDD) and optimum moisture content (OMC). The maximum dry density and optimum moisture content of soils mixed with lime, natural pozzolana and their combinations are reported in Table 5.

The results show that adding lime increased the OMC and reduced the amount of MDD with the increase of lime addition. Similar behaviour was observed by other researchers for lime stabilized clayey soils [16, 18, 31-35]. The following reasons could explain this behaviour: (1) the lime causes aggregation of the particles to occupy larger spaces and hence alters the effective grading of the soils, (2) the specific gravity of lime generally is lower than the specific gravity of soils tested, (3) the pozzolanic reaction between the clay present in the soils and the lime is responsible for the increase in OMC.

Table 5 shows the effect of increasing NP content on both OMC and MDD. The OMC decreased and the MDD increased as NP content increases from 0 to 20%. The increase in dry density is an indicator of improvement of soil properties. Hossain et al. [16] used volcanic ash from natural resources for stabilization of two soils and observed an increase in OMC and a decrease in MDD as volcanic ash content increased from 0 to 20%.

Table 5. Compaction characteristics for stabilized soils

Désignation	Grey soil		Red soil	
	OMC (%)	MDD (kN/m^3)	OMC (%)	MDD (kN/m^3)
P0L0	28.3	13.8	15.3	16.9
P0L4	30.4	13.2	17.8	16.4
P0L8	31.1	12.9	17.4	16.2
P10L0	27.6	14.0	14.3	17.1
P20L0	25.8	14.3	13.8	17.1
P10L4	26.8	13.3	16.6	16.5
P20L4	29.0	13.6	18.7	16.4
P10L8	29.8	13.3	17.7	16.1
P20L8	28.2	13.6	18.2	16.0

The decrease in OMC observed in our study could apparently have resulted from the lower affinity of NP for water. In addition, the increase in MDD is probably attributed to the relatively higher specific gravity of the NP. The addition of a combination of lime and natural pozzolana to the grey soil decreased the OMC and increased the MDD. But, for the red soil the combination of lime and natural pozzolana increased the OMC and reduced the MDD. particularly at 20%NP content. Several researchers [5, 18, 31] found that the change in dry density occurs because of both the particles size and specific gravity of the soil and stabilizer.

3.2. Shear strength

3.2.1. Effect of curing time on shear stress of stabilized ohesive soils

The effect of lime, natural pozzolana and their combinations on maximum shear stress of the grey and red soils for different curing periods is shown in figs. 1and 2, respectively.

Increasing the curing time increased the shear stress of both cohesive soils tested. Addition of lime has a significant effect on shear stress particularly beyond 28 days and in samples containing 8% lime for both grey and red soils tested.

The addition of natural pozzolana alone had a negligible effect on shear stress with increasing curing period for grey soil. However, for the red soil, a marginal increase in shear stress was observed at later ages (90 days).

For samples stabilized with the combination lime-natural pozzolana, there was a considerable increase in shear stress beyond 7 days curing time and particularly at later ages. Moreover, for both soils, the combination 20%NP+8%L exhibited a high increase in shear stress beyond 28 days curing period. This trend was particularly noticed for red soil.

3.2.2 Effect of curing time on shear parameters of stabilized cohesive soils

The effect of lime, NP and their combinations on shear parameters, cohesion and internal friction angle of the grey and red soils for different curing period are shown in figs. 3 and 4 respectively.

In slope stability analyses the maximum shear strength is generally of primary importance. For this reason only the shear parameters using the maximum shear stresses were calculated.

The variation of cohesion with time of grey and red soils is shown in fig. 3(a) and fig. 4(a). Addition of lime had a significant effect on cohesion with the curing period. There is a considerable increase in cohesion at later ages and in samples containing 8% lime. Similar behaviour was found by Gay et al. [34]. This behaviour was due probably to the self-hardening effect related to the lime. Ola [36] considered the

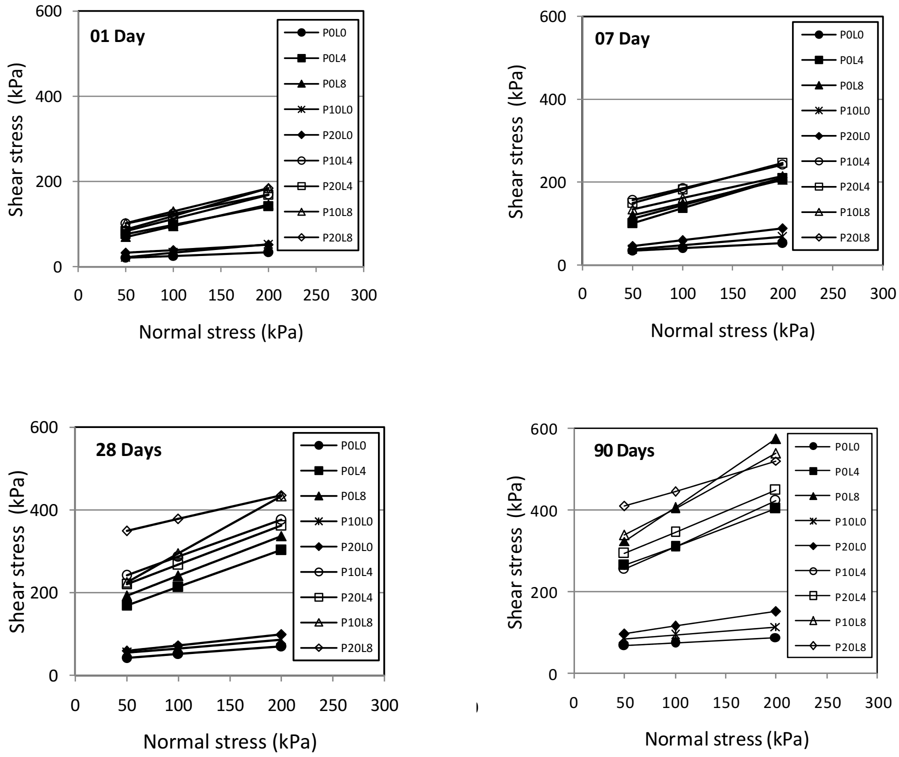

Fig. 1. Variation of shear stress with normal stress of grey soil for different curing time

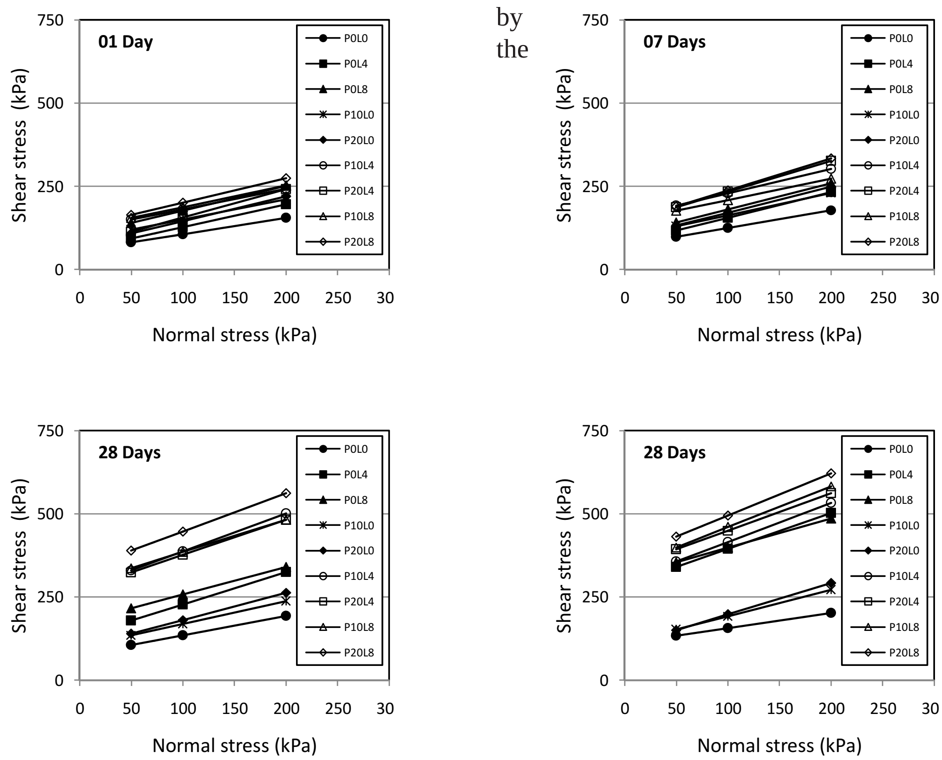

Fig. 2. Variation of shear stress with normal stress of red soil for different curing time

increase in cohesion with increasing lime content, to be due to the bonding of particles into larger aggregates such that the soil behaved as a coarse-grained, strongly bonded, particulate material. Other researchers [37, 38] explained this behaviour cementation and pozzolanic reactions which occur over time.

Addition of natural pozzolana alone had a marginally effect on cohesion with increased curing period. This effect may be slightly pronounced for the grey soil at 90 days age.

However, there is a considerable increase in cohesion at later ages and in samples stabilized with the combination lime-natural pozzolana compared to natural pozzolana-soil alone. Furthermore, and for both soils, the combination 20%NP+8%L exhibited a high increase in cohesion beyond 28 days curing period. This trend was particularly observed for grey soil.

As it can be seen from fig. 3(b) and fig. 4(b), for both stabilized soils the internal friction angle increased with time as lime content increased. However, for the grey soil there was a considerable increase in internal friction angle beyond 28 days curing period. Similar trend was found by Sezer et al. [15]. The latter used very high lime fly ash and they concluded that this behaviour is probably due to the fact that the internal friction angle of the fly ash is more than that of the soil.

On the other hand, the addition of natural pozzolana alone had a marginally effect on internal friction angle with the curing period.

In samples stabilized with the combination lime-natural pozzolana, there is a significant increase in internal friction angle at later ages compared to natural pozzolana-soil alone. However, for the grey soil, the combination 20%NP+8%L had a negligible effect on internal friction angle independent of the curing period.

The improvement in the cohesion and internal friction angle values may be due to pozzolanic activity and self-cementitious characteristics of the combination of lime-natural pozzolana. This behaviour is more pronounced beyond 28 days ages.

4. Conclusions

This paper presented the effect of curing time on shear strength of cohesive soils stabilized with combination of lime and natural pozzolana. On the basis of the tests results from 18 stabilized soil mixtures the following conclusions can be drawn.

- The maximum dry density of lime stabilized soils decreased with increases in lime content, in contrast with natural pozzolana stabilized soils. When a combination lime-natural pozzolana was used, the maximum dry density increased for the grey soil and decreased for the red soil.
- The optimum moisture content of lime stabilized soils increased with increase in lime content, in contrast with natural pozzolana stabilized soils. When a combination lime-natural pozzolana was used, the optimum moisture content decreased for the grey soil and increased for the red soil.
- Increasing the curing time increased the shear stress of both cohesive soils stabilized with lime or with the combination of lime-natural pozzolana. A considerable increase was particularly observed at later ages.

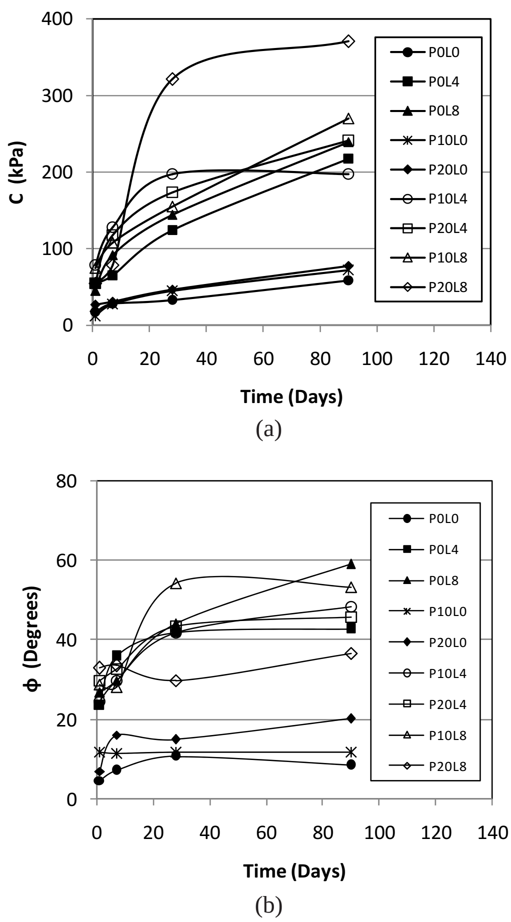

Fig. 3. Variation of shear strength characteristics of grey soil with curing period (a) cohesion and (b) friction angle.

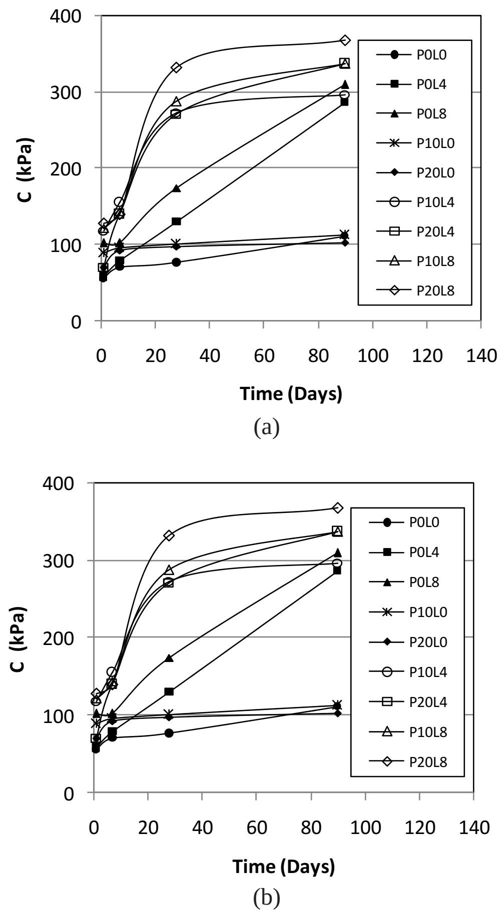

Fig. 4. Variation of shear strength characteristics of red soil with curing period (a) cohesion and (b) friction angle

• There is a considerable increase in cohesion and internal friction angle in samples containing lime with increasing curing period. In addition, a significant increase in cohesion was observed at later ages in samples stabilized with 8% lime content.

• The addition of natural pozzolana resulted in a marginal effect on cohesion and internal friction angle with increasing curing period.

• The combination lime-natural pozzolana exhibited a significant effect on enhancing the cohesion and internal friction angle at later ages. Furthermore and for both soils, the combination 20%NP+8%L exhibited a high increase in cohesion beyond 28 days curing period. This trend was particularly observed for grey soil. On the other hand, the same combination had a negligible effect on internal friction angle independent of the curing period.

• The results indicated appreciable improvement of both stabilized soils. The combination lime-natural pozzolana produced higher shear parameters values than lime or natural pozzolana alone.

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