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Shear Strength of an Expansive Overconsolidated Clay Treated with Hydraulic Binders

A. Mahamedi[1] and M. Khemissa[2]
[1,2]*Geomaterials Development Laboratory, University of M'sila, 28000 M'sila, Algeria*
E-mail: khemissa@univ-msila.dz

ABSTRACT: This paper presents and analyzes the results of a series of identification; compaction and direct shear tests performed in accordance with the Algerian standards on expansive overconsolidated clay treated with locally manufactured hydraulic binders (composed Portland cement and extinct lime). This clay comes from the urban site of Sidi-Hadjrès city (wilaya of M'sila, Algeria), where significant damages frequently appear in the road infrastructures, roadway systems and various networks and in civil and industrial light structures. Tests results show that the geotechnical parameters deduced from these tests are concordant and confirm the shear strength improvement of this natural clay treated with cement or lime and compacted under the optimum Proctor conditions. However, contrary to its mineralogical characteristics which do not seem to be affected by the treatment, this expansive natural clay is characterized by as well drained as undrained shear strength sensitive to stabilizer content; the best performances are obtained for a treatment corresponding to 8% cement or lime content.

KEYWORDS: Expansive clay, Treatment, Hydraulic binders, Shear strength.

1. INTRODUCTION

Expansive soils are a worldwide problem and occur in many parts of the World but particularly in arid and semi-arid regions (Al-Rawas and Goosen, 2006). Arid and semi-arid regions cover a good part of Algeria. They are delimited by the Tellian Atlas in north and the Saharian Atlas in south and extend from east to west until the bordering Maghreb's countries. Khemissa et al. (2015) exposed a bibliographical synthesis of the principal experimental studies carried out on some expansive soils collected in these zones, in particular on the M'sila expansive clays.

Urban areas of the wilaya of M'sila in Algeria nowadays experience a considerable development because of an unceasingly increasing demography, from where its extension towards virgin zones often less favorable than those already urbanized. This wilaya is located in a zone classified as semi-arid. This zone is characterized by weak precipitations and significant variations in temperature between winter and summer (cold and wet winters and hot and dry summers, see Figure 1). Geology of this zone comprises clays formations characterized by a high variation of volume when the conditions of their equilibrium are modified (natural climatic phenomena due to a prolonged dryness, human activity by modification of the ground water level because of excessive pumping, configuration of constructions in their environment). A former study exposed by Khemissa et al. (2008) shows that these natural clays are very over-consolidated, low permeable and very low sensitive to creep; their overconsolidation being due to the phenomenon of shrinkage resulting from a more-or-less thorough desiccation. The use in fills and in base and sub-base courses, in the natural state of this clay, is normally not considered. At dry state, it is very difficult to compact since its consistency varies from hard to very hard and, at wet state, it is very sticking. However, its employment can be possibly decided on basis of specific treatment with hydraulic binders (LCPC-SETRA, 2000a). This process is mainly used to make compactable the soft soils by reduction of their plasticity and, consequently, to improve their bearing capacity. Limes mainly calcic (quicklime, extinct lime, lime slurry), cements and special road binders are the most used treatment products. The action of these products on the hydrous state of fine-grained soils and on their clayey fraction is highlighted in practice. Treatment studies on some expansive soils confirm also the action of the cement and lime on their geotechnical characteristics (Khemissa and Mahamedi 2014). However, the effect of the treatment with hydraulic binders on the shear characteristics of expansive soils is not yet clearly elucidated.

This paper presents the results of a study carried out on expansive clay obtained from a site situated in Sidi-Hadjrès city (wilaya of M'sila, Algeria), where significant disorders frequently appear in the road infrastructures, roadway systems and various networks and in the civil and industrial small buildings. Study carried out aims at determining the physical and mechanical parameters of this clay treated with locally manufactured hydraulics binders (composed Portland cement and extinct lime). Influence of treatment on its shear and rupture characteristics is then analyzed.

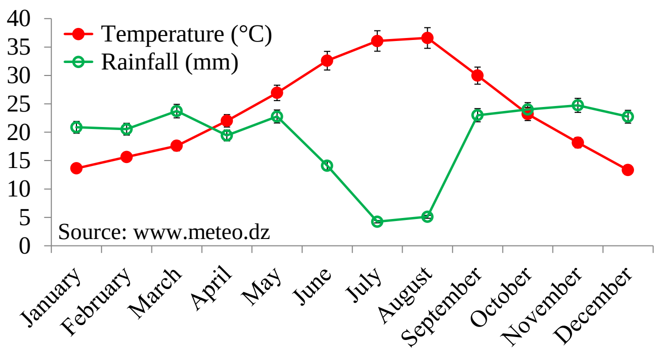


Figure 1 Meteorology of the wilaya of M'sila (Algeria)

2. DESCRIPTION OF THE STUDIED CLAY

The soil samples used were collected between 1.3 and 1.7 m of depth in a yellowish-brownish gypsums marl clayey layer reaching 1.5 to 4.5 m of depth according to places. Figures 2, 3 and 4 show respectively the grading curve, the typical compaction curve and the XRD test results of this natural clay. Identification tests were conducted on the tested samples in accordance with Algerian standards compatible to French standards. Table 1 presents their chemical composition. Table 2 gives the variation ranges and the mean values of their geotechnical parameters.

These low dispersed values for the carried out sampling seem to indicate a homogeneous soil massif. The grading curve of tested soil samples indicates that they are composed of 25% sand, 50% silt and 25% clay. According to Bureau of soils triangular chart for textural classification, these soils can be classified as silty clay. According to French classification, compatible to the Unified Soil Classification System (USCS), it is about a high plastic clay (CH), very consistent with important activity of its clayey fraction (presence of calcic montmorillonite). Chemical analysis conducted on this clay shows that the dominating elements are silica, carbonates and alumina. X-ray diffractogram shows that the silica is crystallized in the form of quartz (21%) and carbonates in the form of calcites (79%).

According to French classification for fine-grained soils and evolutionary rock materials (LCPC-SETRA, 2000b), this clay belongs to the A4 subclass (I_p>40 or VBS>8) and it is considered as low fragmentary (FR<7) and low damaged (DG<5). On the other hand, the modifications of its water content are accompanied by shrinkage or swelling. The Casagrande plasticity chart adapted to expansive soils shows that this clay is characterized by a high swelling potential according to Dakshanamurthy and Raman (1973) classification and by a high-to-very high swelling potential according to Chen (1988) classification (Figure 5). Also, classifications of Seed et al. (1962), Ranganatam and Santyanarayana (1965), Williams and Donaldson (1980) and Bigot and Zerhouni (2000) indicate a very high swelling potential. In addition, the Building Research Establishment classification (BRE-UK, 1980) led to a very high shrinkage potential.

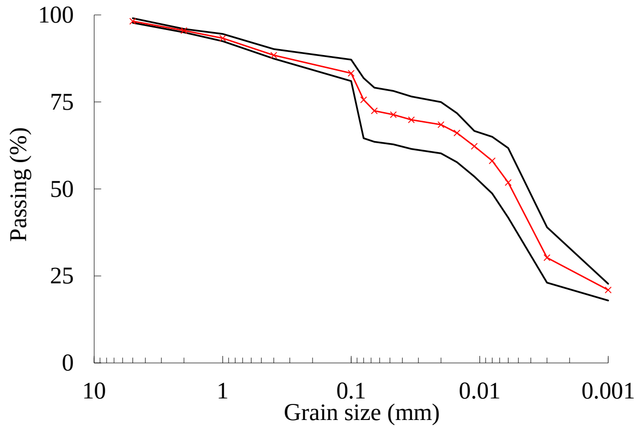


Figure 2 Grading curve of Sidi-Hadjrès clay

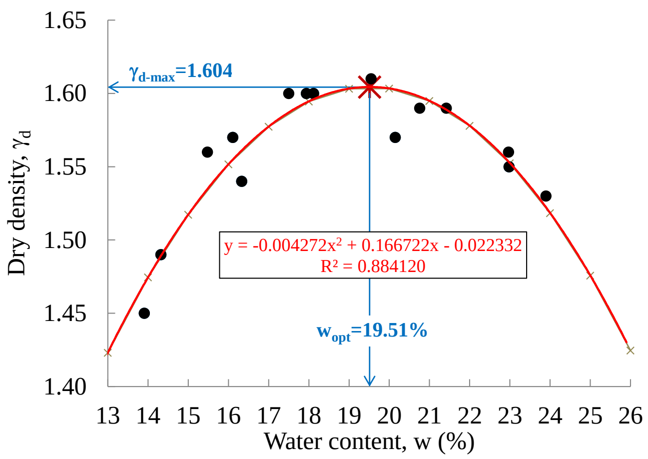


Figure 3 Typical compaction curve of Sidi-Hadjrès clay

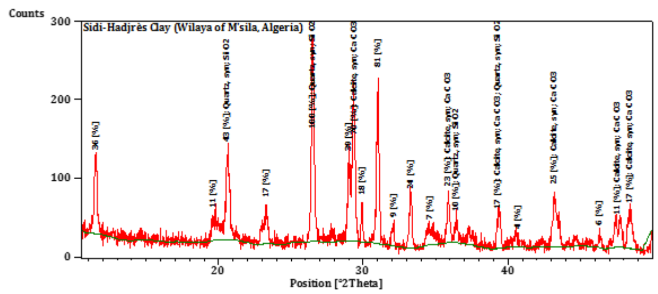


Figure 4 X-ray diffractogram of Sidi-Hadjrès clay

Table 1 Chemical composition of Sidi-Hadjrès clay

Constituents	%
SiO_2	43.38
CaO	14.66
MgO	02.55
Fe_2O_3	04.02
Al_2O_3	11.36
SO_3	11.55
K_2O	01.51
Na_2O	01.12
Loss on ignition	10.03

Table 2 Geotechnical parameters of Sidi-Hadjrès clay

Parameters	Variation ranges	Mean values
Depth, z (m)	01.30 - 01.70	01.50
Moisture content, w_{nat} (%)	13.21 - 13.46	13.34
Wet unit weight, γ_h (kN/m^3)	20.40 - 24.20	22.30
Dry unit weight, γ_d (kN/m^3)	18.00 - 21.40	19.70
Liquid limit, w_L (%)	81.50 - 86.70	83.70
Plastic limit, w_P (%)	30.60 - 36.60	32.80
Plasticity index, I_P (%)	50.10 - 51.90	51.00
Consistency index, I_c (%)	01.33 - 01.47	01.38
Methylene blue value, VBS (%)	07.40 - 09.77	08.31
Over to 2 mm	95.00 - 96.00	95.50
Over to 0.08 mm	64.60 - 81.90	73.20
Over to 2 µm, C_2 (%)	20.50 - 30.90	25.70
Clay activity, A_c	01.95 - 02.02	01.98
Optimum water content, w_{opt} (%)	19.20 - 19.60	19.51
Maximum dry density, γ_{d-max}	01.59 - 01.61	01.60
Damage coefficient, DG	02.68 - 03.50	02.97
Fragmentability coefficient, FR	02.93 - 03.51	03.25

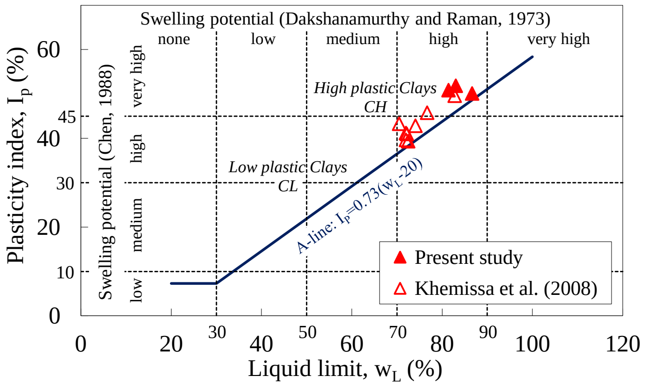


Figure 5 Classification of Sidi-Hadjrès clay

3. EXPERIMENTAL PROGRAM

In addition to identification tests, the experimental program comprises modified Proctor compaction tests, California bearing ratio tests and direct shear tests by using a shear box comparable to Casagrande shear box. Shear tests made are of consolidated undrained type (CU-tests) and of consolidated drained type (CD-tests) performed on saturated or unsaturated samples after their compaction under the optimum Proctor conditions. These tests were performed on untreated soil (control sample) and on treated soil with various contents of a composed Portland cement and an extinct lime. The cement is locally manufactured by the Lafarge Company of Hammam Dalâa (wilaya of M'sila, Algeria). The extinct lime comes from the ERCO Company of Hassasna (wilaya of Saïda, Algeria). Tables 3 and 4 give respectively the physico-chemical properties of these two stabilizers.

Stabilizer contents considered (cement or lime) are 0% for untreated sample (control sample), 2%, 4%, 6%, 8%, 10% and 12% by dry soil weight for treated samples. The samples were made starting from mixture of the necessary quantity of finely crushed dried soil to desired stabilizer content; the whole being intimately mixed at dry then humidified with optimum water content w_{opt} (i.e. maximum dry density $\gamma_{d\text{-}max}$ corresponding to optimum Proctor). The paste was remixed thoroughly before performing the compaction. All tests were conducted at room temperature between 20 and 25 °C.

Table 3 Physico-chemical properties of the cement

Designation	CEM-II/B 42.5 N NA 442 – MATINE	
Physical properties	Normal consistency	25 - 28.5
	Blaine Fineness (µm/m)	4150 - 5250
	Initial setting (min)	140 - 195
	End setting (min)	195 - 290
	Shrink at 28 days of age (µm/m)	< 1000
	Expansion (mm)	0.3 - 2.5
	Compressive strength (MPa)	≥ 42.5
Chemical composition	Loss on ignition (%)	7.5 - 12
	Soluble residues (%)	0.7 - 2
	Sulfates (%)	2 - 2.7
	Magnesium Oxide (%)	1 - 2.2
	Chlorides (%)	0.01 - 0.05
	Tricalcic Silicates (%)	55 - 62
	Alkalis (%)	0.5 - 0.75

Table 4 Physico-chemical properties of the lime

Designation	NHL	
Physical properties	Bulk density (g/l)	600 - 900
	Absorption coefficient	< 5
	Sensitivity to freezing	< 30
	Volume of extinction (cm^3)	2.73
	Over 630 µm (%)	0
	Over 90 µm (%)	< 10
Chemical composition	Humidity	< 5
	CaO (%)	> 83.3
	MgO (%)	< 0.5
	Fe_2O_3 (%)	< 2
	Al_2O_3 (%)	< 1.5
	SiO_2 (%)	< 2.5
	SO_3 (%)	< 2.5
	Na_2O (%)	< 4.7 - 0.5
	CO_2 (%)	< 5
	$CaCO_3$ (%)	< 10
	Insoluble in HCl (%)	< 1

Experimental procedures followed in each test type were in conformity as much as possible with the Algerian usual testing methods. The interpretation techniques of the test results are many inspired from the knowledge obtained on clayey soils throughout the World. Figure 6 shows the modified Proctor compaction test results (maximum dry density $\gamma_{d\text{-}max}$ and optimum water content w_{opt}) conducted on the clay treated with various cement and lime contents under the optimum Proctor conditions. These results constitute a pledge of good repeatability of the compaction test. They indicate a good reconstitution of the soil in-situ as in laboratory under the stresses to which it is subject.

4. TEST RESULTS AND DISCUSSION

Only the principal test results interesting the object of this paper (i.e. influence of the simple cement and lime treatment on the mineralogical and plasticity characteristics of the clay compacted under the optimum Proctor conditions and on its deformability and strength parameters) are presented hereafter.

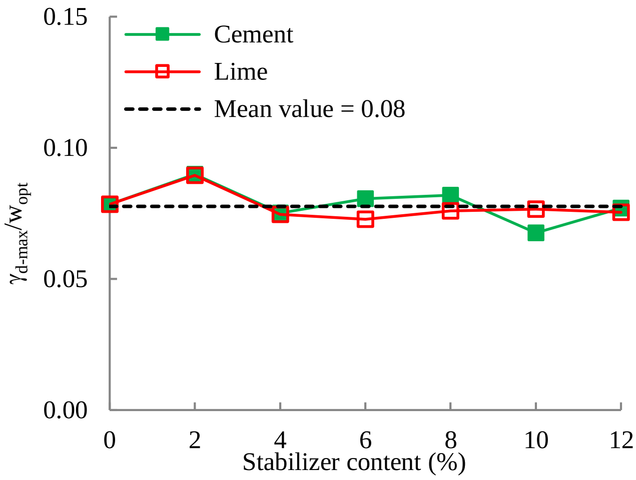


Figure 6 Compaction test results of the stabilized Sidi-Hadjrès clay

4.1 Treatment effect on the mineralogy of the clay

Figure 7 shows the evolution diagrams of the principal clay minerals determined by XRD method before and after treatment with various cement or lime contents and its compaction under the optimum Proctor conditions. One can note that the treatment with hydraulic binders of this expansive natural clay does not affect considerably its mineralogical characteristics, so that the calcite and quartz contents do not seem to evolve to a significant degree. In other words, the form and the assembly of these two types of dominating minerals are very little assigned by the lime or cement addition to clay before being compacted under the optimum Proctor conditions.

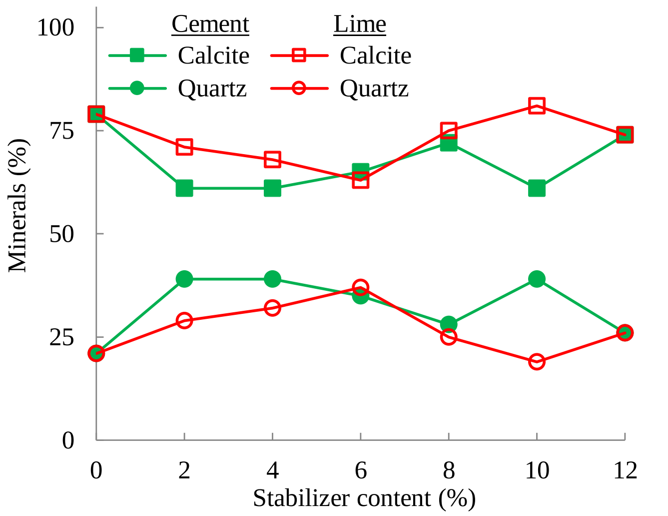


Figure 7 Treatment effect on the mineralogy of the clay

4.2 Treatment effect on the plasticity of the clay

Figure 8 shows that the plasticity index and the liquid limit decrease with used stabilizer contents, but more with lime than with cement. This reduction results in a reduction of the plasticity of the clay which becomes less sensitive to water, therefore better compactable, with in premium a weaker swelling potential. The swelling reduction of treated clay gets a certain stability with respect to the deformations due to the seasonal variations of water content and, consequently, a durable behavior (with respect to the wear of the particles generating of plastic fine particles).

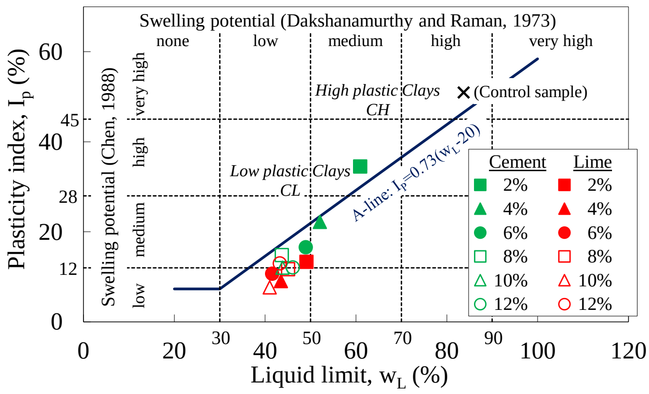


Figure 8 Treatment effect on the plasticity of the clay

4.3 Treatment effect on the bearing capacity of the clay

Figure 9 shows the evolution diagrams of the soaked and unsoaked CBR of the clay treated with various cement or lime contents and compacted under the optimum Proctor conditions. One can note an increase in these two parameters with stabilizer contents, but more with cement than with lime for the unsoaked CBR and reciprocally for the soaked CBR.

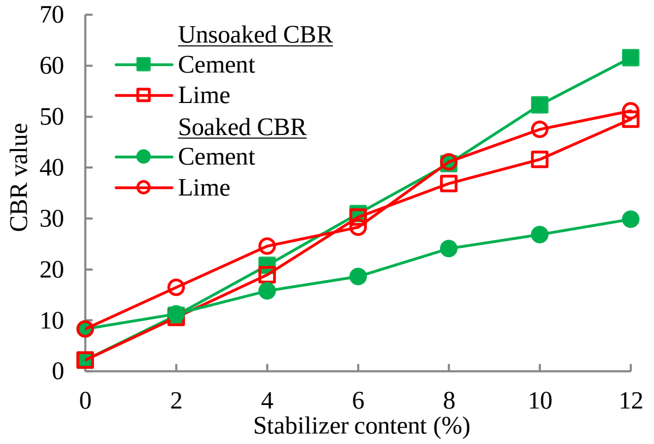


Figure 9 Treatment effect on the bearing capacity of the clay

4.4 Treatment effect on the shear strength of the clay

Figures 10 and 11 show the evolution curves of drained (c' and φ') and undrained (c_{cu} and φ_{cu}) shear parameters of the clay treated with various cement or lime contents and compacted under the optimum Proctor conditions. These parameters correspond to the direct shear curves peaks. One can note that the cohesion and interne friction angle values (i.e. the shear strength) of saturated soil are less than those of unsaturated soil, as well treated as untreated. However, the evolution of these parameters is not regular for both stabilizers.

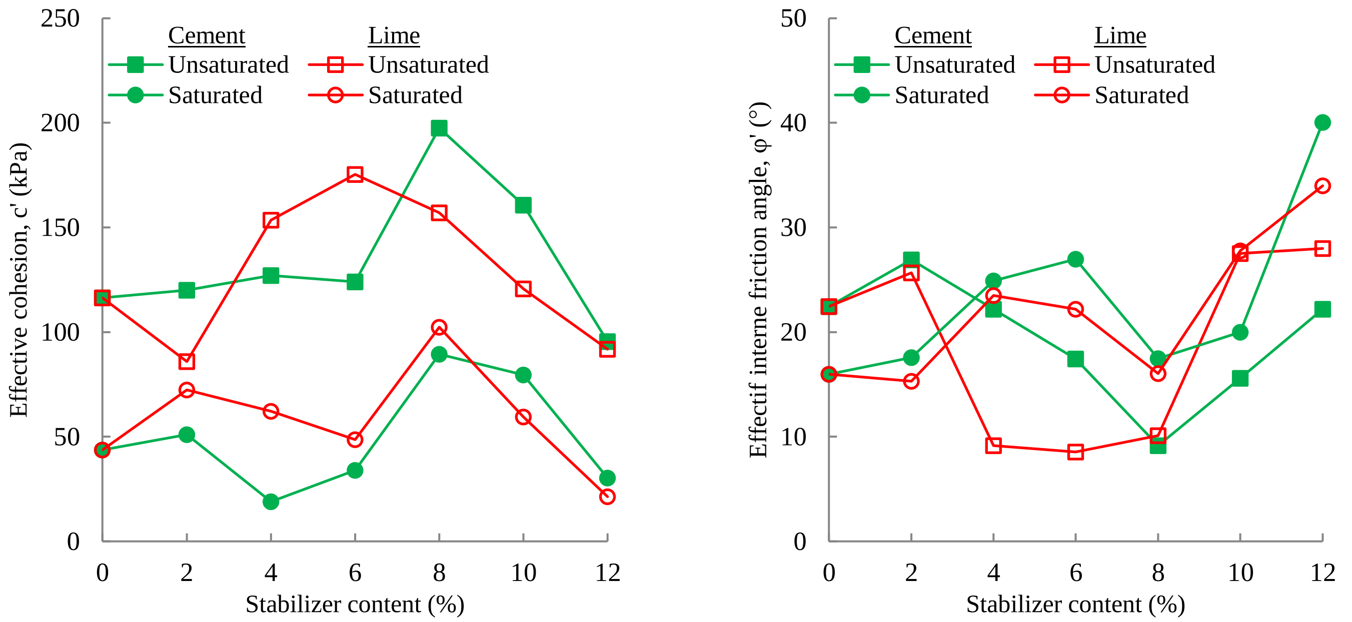


Figure 10 Treatment effect on the drained shear strength of the clay

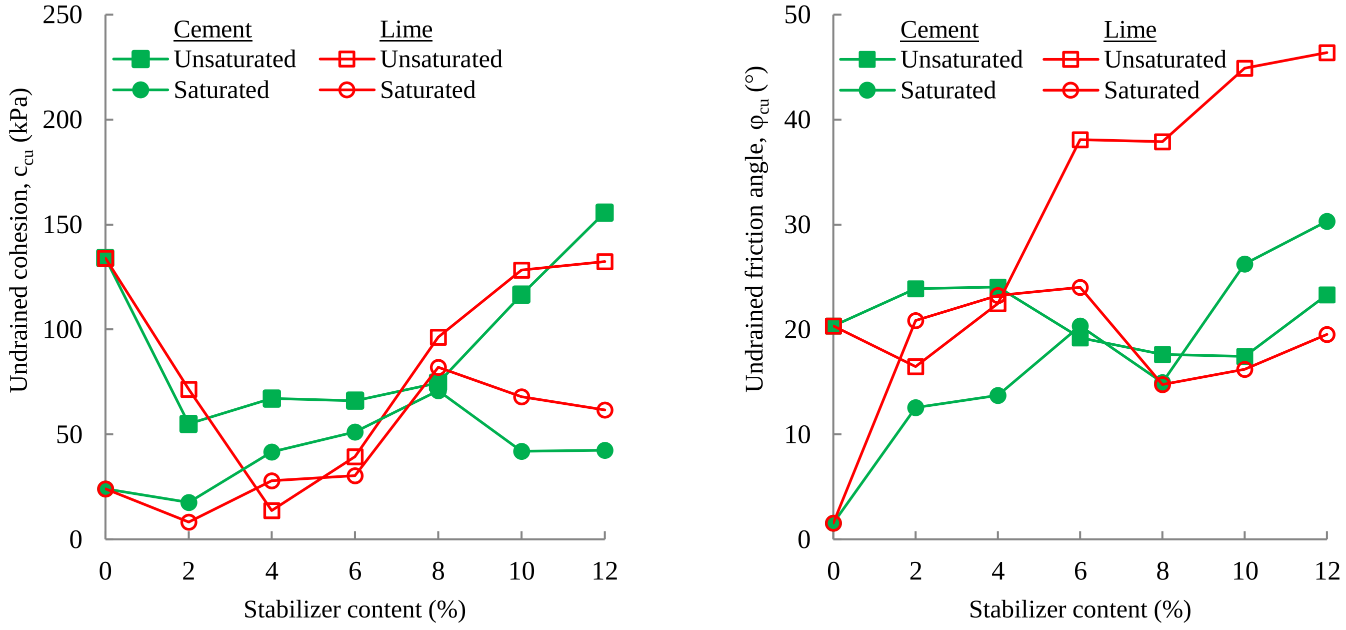
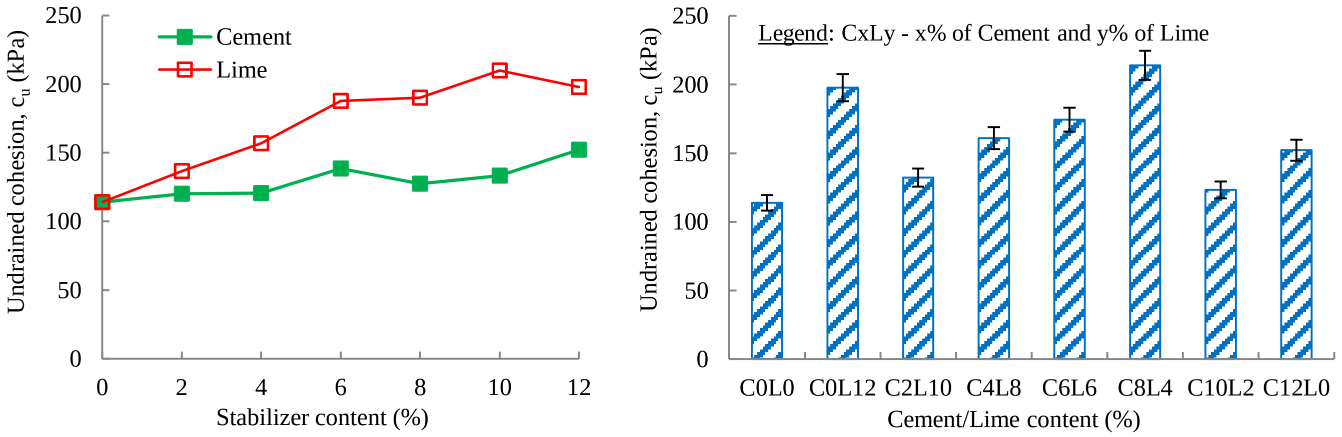


Figure 11 Treatment effect on the undrained shear strength of the clay

The examination of the preceding curves makes it possible to note that the treatment effect of this expansive natural clay becomes effective only starting from a 4% of lime or cement contents, but more for the unsaturated soil than for the saturated soil. In all the cases, the optimal values of drained and undrained shear parameters are obtained for a treatment corresponding to 8% of cement or lime. However, it is necessary to compile many data on the same soil type in order to understand why one obtains a greater strength corresponding to 8% of cement or lime content than by using a greater content. In addition, a former study carried out on this same clay treated with same stabilizers (Khemissa and Mahamedi, 2014; Mahamedi and Khemissa, 2015) shows that the undrained cohesion c_u (corresponding to the unconsolidated and undrained direct shear tests: UU-tests) increases with stabilizer content, as well for the simple treatment as for the mix treatment (Figure 12). This result is translated, in both cases, by a clear improvement of the bearing capacity of the clay. This improvement is more obtained for the simple treatment with lime than with cement. The best result is obtained for a mix treatment corresponding to 8% of cement and 4% of lime contents.



a/ Simple treatment *b/ Mix treatment*

Figure 12 Simple and mix treatment effect on the undrained cohesion of the clay

5. CONCLUSION

This paper has the aim of characterizing the behavior of an expansive overconsolidated clay treated with locally manufactured stabilizers (composed Portland cement and extinct lime) for its use to the construction of pavement base layers. Choice of Sidi-Hadjrès urban site (wilaya of M'sila, Algeria) was justified because of its extension towards zones at risk, where significant damages frequently appear in the road infrastructures, roadway systems and various networks and in civil and industrial light structures. Tested soil samples were identified as high plastic clay. Various classifications based on the geotechnical properties show that this clay is characterized by a very high swelling potential; swelling being to some extent due to the mineralogical structure of soils (high percentage of montmorillonite) and to the variations of their water content (desiccation-humidification cycles of soils). Obtained test results allow to conclude that the simple treatment with hydraulic binders improve the shear strength of the clay, so its bearing capacity, but more with the lime that with cement. The best performances were obtained for a mix treatment corresponding to 8% cement and 4% lime contents. However, these results constitute only a first approximation which requires the realization of many tests to be elucidated better.

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