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Cement and Lime Stabilization Effect on the Evolutivity of an Expansive Overconsolidated Clay

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Abstract: This paper presents and analyzes the results of a series of compaction, fragmentability and damage tests performed on an expansive overconsolidated clay treated with cement and lime. This clay was obtained from the urban site of Sidi-Hadjrès city (wilaya of M'sila, Algeria), where significant damages frequently appears in the road infrastructures, roadway systems and light structures. Tests results obtained show that the geotechnical parameters values deduced from these tests are concordant and confirm the evolutivity of this natural clay treated with composed Portland cement or extinct lime and compacted under optimum Proctor conditions.

Key words: Expansive clay, evolutivity, treatment, cement, lime, fragmentability coefficient, damage coefficient.

1. Introduction

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, characterized by weak precipitations and significant variations in temperature between winter and summer (cold and wet winters and hot and dry summers). 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 conducted by Khemissa et al. (2008) [1] shows that this zone comprises clayey formations classified as overconsolidated, low permeable and very low sensitive to creep. Their overconsolidation is due to the phenomenon of shrinkage resulting from more-or-less thorough desiccation. Use to the construction of pavement base layers, in the natural state of this clay, is normally not considered. At dry state, it is very difficult to compact because its consistency varies from hard to very hard and, at wet state, it is very sticking. However, its employment can be possibly decided on the basis of specific treatment with lime and/or hydraulic binders [2]. However, the clayey rock's treatment with cement or lime can have consequences on their evolutivity, because their structure changes under effect of loadings applied by the compacting machines during earthworks and under action of mechanical stresses or hydrous state's modifications which they can undergo. The road earthwork's technical guide in use in France [3] recommends using the fragmentability and damage coefficients like parameters of the mechanical behavior in classification of clayey rocks from the point-of-view of their evolutivity. Interpretation of these two parameters aims at the employment possibilities as backfills of evolutionary rock materials, for which the Los Angeles and Micro Deval coefficients miss sensitivity in presence of water.

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

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significant damages frequently appear in the road infrastructures, roadway systems and light structures. Study carried out aims at analyzing the influence of the treatment on the evolutivity characteristic parameters of this expansive natural clay treated with hydraulic binders (composed Portland cement and extinct lime).

2. Summary Description of the Studied Clay

The soil samples used were collected between 1.3 and 1.7 m of depth in a layer of yellowish brown gypseous marly clay, reaching 1.5 to 4.5 m of depth according to the places. Tables 1 and 2 give the identification test results carried out on these soil samples and their chemical composition respectively. Figure 1 shows their grain size distribution curve. Fig. 2 shows their X-ray diffraction test results. These low dispersed values for the carried out sampling seem to indicate a homogeneous soil massif. According to USDA textural classification system, they are classified as clay loam. According to French classification [4], compatible to Unified Soil Classification System (USCS), they are classified as high plastic (CH) and very consistent clay (I_c>1) with important activity of its clayey fraction (A_c>1.25; 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 quartz form (21%) and the carbonates are crystallized in calcites form (79%). According to French classification for fine-grained soils and evolutionary rock materials [3], this clay belongs to A4 subclass (I_p>40 or MBV>8: high plastic clays and marly clays) 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. Casagrande plasticity chart adapted to expansive soils according to Dakshanamurthy and Raman (1973) [5] and Chen (1980) [6] classifications shows that this clay is characterized by a high-to-very high swelling potential (Fig. 3). Seed et al. (1962) [7], Ranganatam and Santyanarayana (1965) [8], Williams and Donaldson (1980) [9] and Bigot and Zerhouni (2000) [10] classifications also indicate a very high swelling potential. In addition, BRE-UK (1980) [11] classification led to a very high shrinkage potential.

Table 1 Geotechnical properties of Sidi-Hadjrès clay (wilaya of M'sila, Algeria).

Parameters	Range of variation	Mean values
Depth, z (m)	1.30-1.70	1.50
Natural water content, w_{nat} (%)	13.21-13.46	13.34
Wet unit weight, g_h (kN/m^3)	20.4-24.2	22.3
Dry unit weight, g_d (kN/m^3)	18.0-21.4	19.7
Liquid limit, w_L (%)	81.5-86.7	83.7
Plastic limit, w_P (%)	30.6-36.6	32.8
Plasticity index, I_P (%)	50.1-51.9	51.0
Consistency index, I_c (%)	1.33-1.47	1.38
Methylene blue value, MBV	7.40-9.77	8.31
Over to 2 mm	95.0-96.0	95.5
Over to 0.08 mm	64.6-81.9	73.2
Clay content, C_{2mm} (%)	20.5-30.9	25.7
Activity of clay, A_c	1.95-2.02	1.98
Optimum water content, w_{opt} (%)	19.2-19.6	19.43
Maximum dry density, g_{d-max}	1.59-1.61	1.60
Fragmentability coefficient, FR	2.93-3.51	3.26
Damage coefficient, DG	2.68-3.50	2.97

Table 2 Chemical composition of Sidi-Hadjrès clay (wilaya of M'sila, Algeria).

Constituents	SiO_2	CaO	MgO	Fe_2O_3	Al_2O_3	SO_3	K_2O	Na_2O	L.O.I
%	43.38	14.66	2.55	4.02	11.36	11.55	1.51	1.12	10.03

L.O.I – Loss on ignition

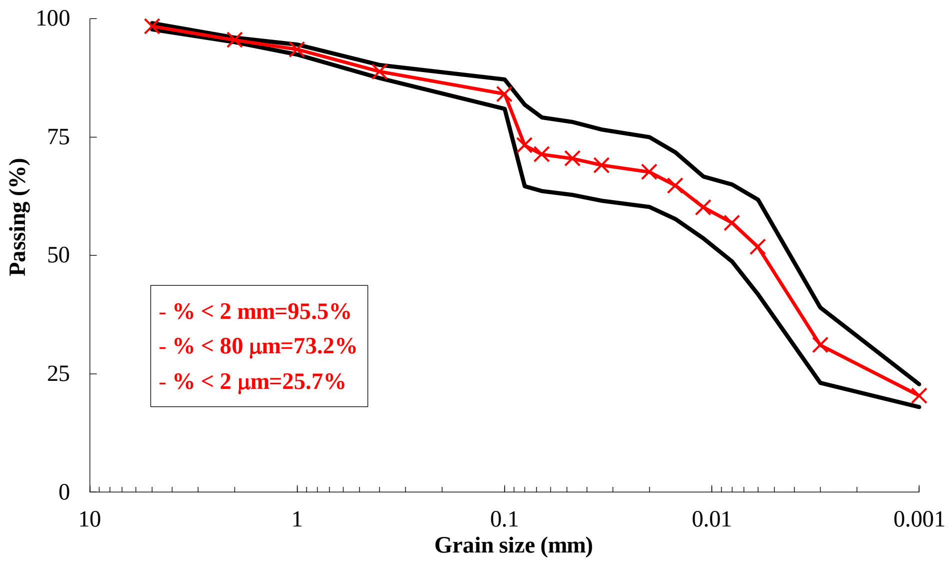

Fig. 1 Grain size distribution curve of Sidi-Hadjrès clay (wilaya of M'sila, Algeria).

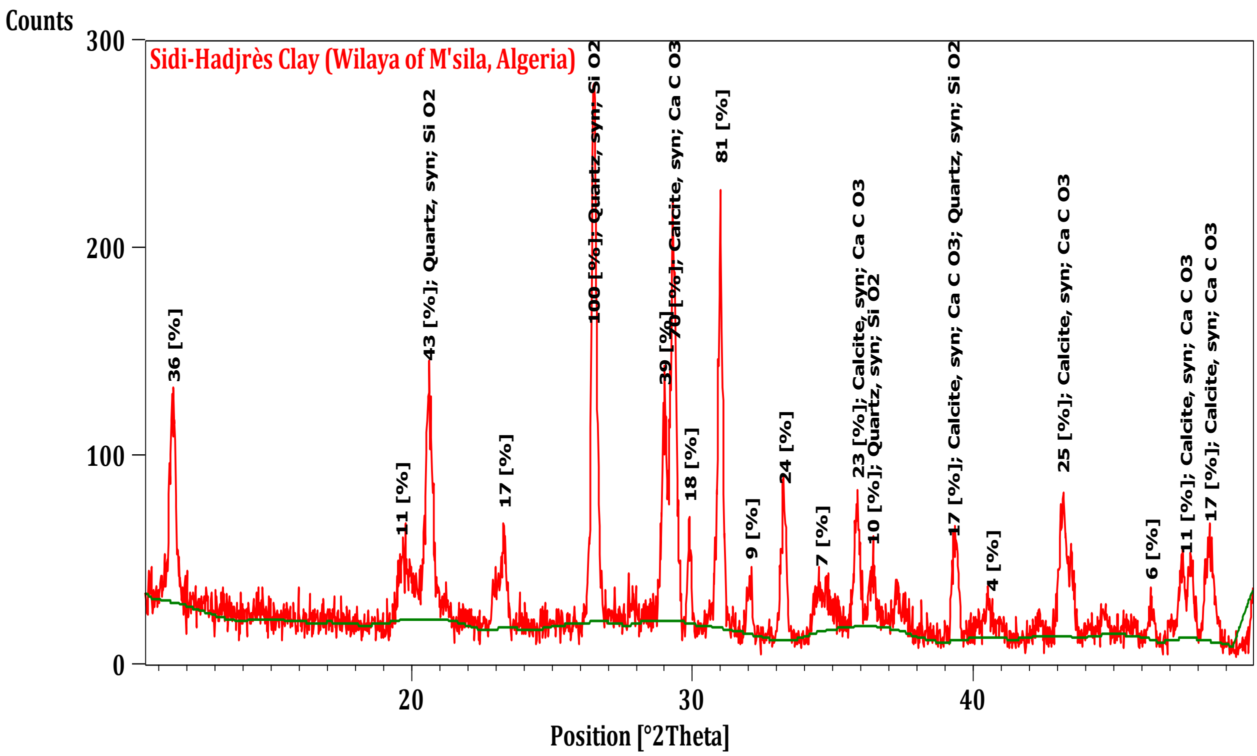

Fig. 2 X-ray diffractogram of Sidi-Hadjrès clay (wilaya of M'sila, Algeria).

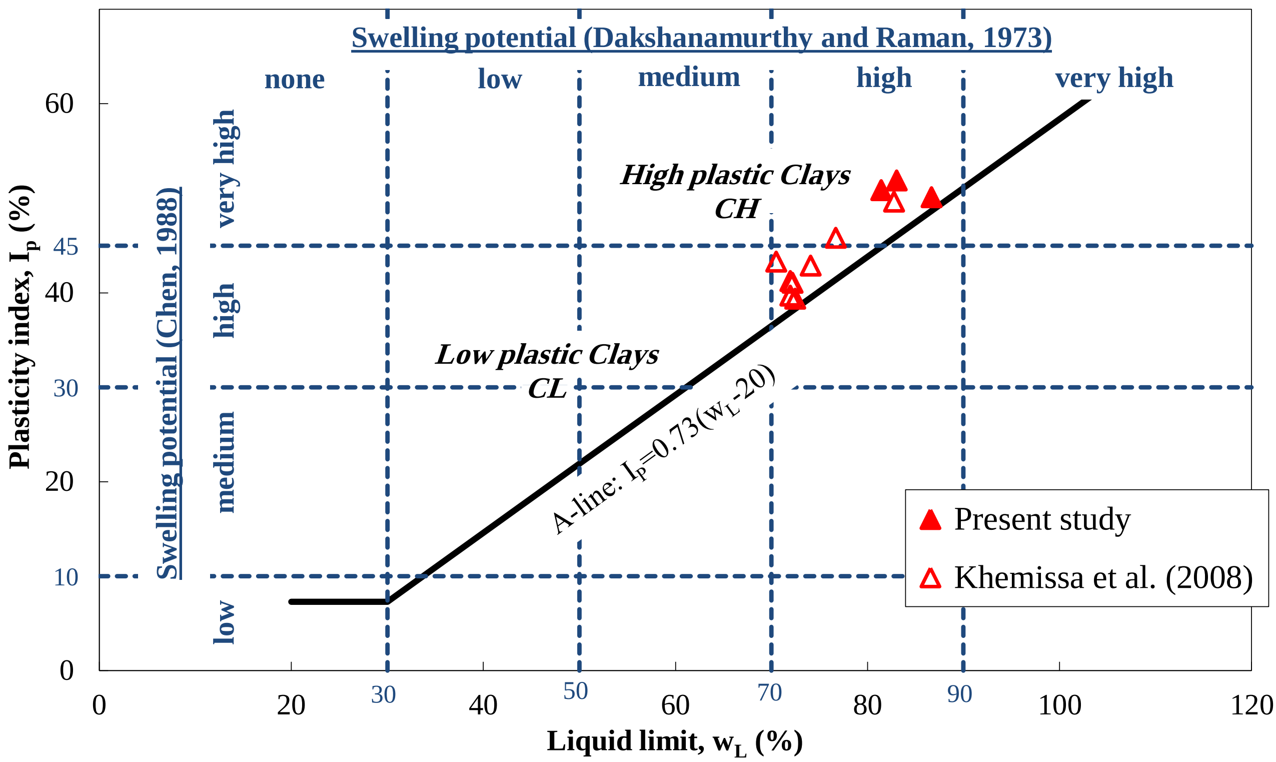

Fig. 3 Classification of Sidi-Hadjrès clay (wilaya of M'sila, Algeria).

3. Experimental Program and Test Procedures

In addition to identification tests, the executed experimental program comprises normal Proctor compaction tests, fragmentability tests and damage tests performed in accordance with Algerian standards [12] comparable to French standards. These tests were carried out on untreated soil (control sample) and on treated soil with various cement or lime contents. Used composed Portland cement is locally manufactured in Lafarge's company of Hammam Dalâa (wilaya of M'sila, Algeria). Used Extinct lime comes from ERCO's company of Hassasna (wilaya of Saïda, Algeria). Tables 3 and 4 give the physico-chemical properties of these two stabilizers.

Cement or lime contents considered are 0% for untreated sample (control sample), 2%, 4%, 6%, 8%, 10% and 12% by dry soil weight for treated samples. The soil samples were made starting from a 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 $\gamma_{d\text{-}max}$). The paste was remixed thoroughly before performing the compaction. All tests were conducted at room temperature.

Table 3 Physico-chemical properties of M'sila's composed Portland cement (Algeria).

Designation	CEM-II/B 42.5 N NA 442 - MATINE	
Physical properties	Normal consistency of the cement paste	25-28.5
	Blaine Fineness	4150-5250 mm/m
	Initial setting	140-195 min
	End setting	195-290 min
	Shrink at 28 days of age	< 1000 mm/m
	Expansion	0.3-2.5 mm
	Compressive strength at 28 days of age	≥ 42.5 MPa
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 Saïda's extinct lime (Algeria).

Designation	NHL	
Physical properties	Bulk density	600-900 g/l
	Absorption coefficient	< 5
	Sensitivity to freezing	< 30
	Volume of extinction	2.73 cm^3
	Over 630 mm	0%
	Over 90 mm	< 10%
Chemical composition	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%
	Insolubles in HCl	< 1%

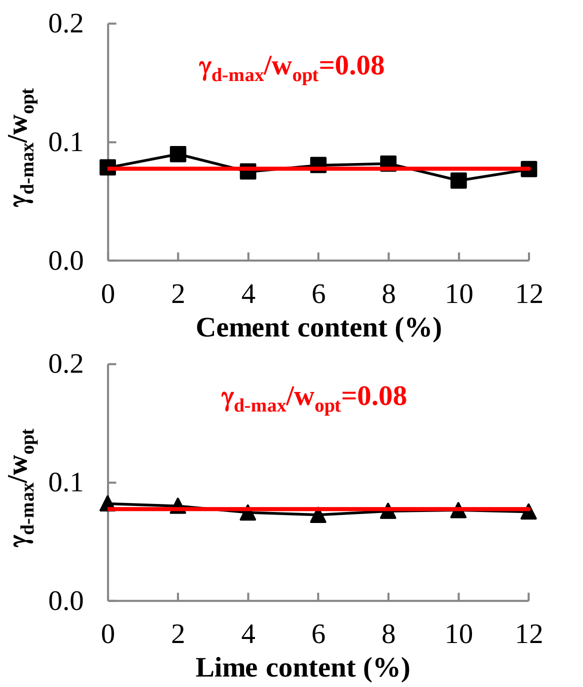

Fig. 4 Normal Proctor compaction test results for various cement or lime contents.

Test procedures followed in each test type were in conformity as much as possible with the usual testing methods in accordance with the corresponding Algerian standards. Interpretation techniques of the test results are many inspired from the knowledge obtained on clayey soils throughout the world.

Fig. 4 shows the normal Proctor compaction test results conducted on the clay treated with various cement or lime contents under optimum Proctor conditions ($\gamma_{d\text{-}max}$ and w_{opt} given on untreated soil). It can be noted that the various dosages do not involve significant differences on the compacting parameters, so that their ratio remains constant ($\gamma_{d\text{-}max}/w_{opt}=0.08$). It can be also noted that these results constitute a pledge of good repeatability of the compaction test and indicate a good reconstitution of the soil under the necessary conditions to which the soil massif is expected to be subjected in-situ.

4. Test Results and Discussion

Only the principal test results interesting the object of this paper are exposed hereafter, i.e. influence of the cement or lime treatment on the evolutivity of the studied clay.

4.1 Fragmentability Coefficient (FR)

Purpose of the fragmentability test is to determine the probability of rock materials to split up under effect of applied loads. Fragmentability coefficient, FR, is defined by ratio of the diameters of grains corresponding to 10% passing measured before and after a conventional ramming with normal Proctor hammer. According to French classification for fine-grained soils and evolutionary rock materials [4], the selected threshold is FR=7 so that:

- if FR<7, the material is considered as low fragmentary;
- if FR>7, the material is considered as fragmentary.

Table 5 gives the FR-values obtained for each considered cement or lime content. It can be noted that the clay remains little fragmentary until 8% cement content, but becomes fragmentary beyond this value. However, the tests carried out on samples treated with lime did not make it possible to obtain measurable values.

Table 5 Classification of the treated clay according to its fragmentability coefficient.

Stabilizer contents (%)	0	2	4	6	8	10	12
Cement	3.25	3.07	3.36	3.91	5.89	9.37	9.90
	low fragmentary					fragmentary	
Lime	3.25	non measurable					
	low fragmentary	-					

Table 6 Classification of the treated clay according to its damage coefficient.

Stabilizer contents (%)	0	2	4	6	8	10	12
Cement	2.97	2.97	2.97	2.97	2.97	3.58	6.31
	low damaged						fairly damaged
Lime	2.97	non measurable					
	low damaged	-					

4.2 Damage Coefficient (DG)

Purpose of the damage test is to determine the probability of rock soils to be damaged under effect of climatic or hydro-geologic actions (frost, drying-imbibition cycles) and of applied loads. Damage coefficient, DG, is defined by ratio of the diameters of grains corresponding to 10% of passing measured before and after drying-imbibition cycles. According to French classification for fine-grained soils and evolutionary rock soils [4], the selected thresholds are DG=5 and DG=20 so that:

if DG<5, the material is considered as low damaged;

if 5<DG<20, the material is considered as fairly damaged;

if DG>20, the material is considered as damaged.

Table 6 gives the DG-values obtained for each considered cement or lime content. It can be noted that the clay remains little damaged up to 10% cement content, but becomes fairly damaged beyond this value. However, the tests carried out on samples treated with lime did not make it possible to obtain measurable values.

5. Conclusions

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 light **structures**. The 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 make it possible to conclude that the treatment with hydraulic binders causes increasing of the fragmentability and damage coefficients. These results seem to indicate that the structure of treated clay evolves from little fragmentary and little damaged states to fragmentary and fairly damaged states; this observation being checked on cement but not on lime for which no measurable value was obtained.

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