PONTE
Vol. 76 No. 2, 2020
*ISSN:*0032-423X*E-ISSN:*0032-6356
Florence, Italy
International Journal of Sciences and Research

DOI: 10.21513/j.ponte.2020.06.11

EFFECT OF DUNE SAND AND LIME ON THE STABILISATION OF SWELLING SOILS. CASE OF CLAYS IN THE ADRAR REGION (ALGERIA)

Khedidja Belaidi[a], Mohamed Amine Allal[a], Belkacem Mekerta[b] & Mohamed Benabdelfattah[b]
[a]University of Tlemcen, BP 230, 13000Tlemcen, **ALGÉRIA**
EOLELaboratory (Eau et Ouvrage dans Leur Environnement)
[b] Ahmed Draia University, 01000 Adrar, **ALGÉRIA**
khadidja.univ@yahoo.fr / khedidja.belaidi@univ-adrar.dz

ABSTRACT

This article presents a series of laboratory tests intended to assess the effect of dune sand and lime on characteristics, such as compaction, free swelling, swelling pressure and hydraulic conductivity, of swelling clay from the region of Adrar(Algeria). The oedometer tests were carried out at different rates of sand and lime, between 2 and 12%, separately, in order to design engineered barriers meant for the realization of the bottom walls of waste disposal facilities. The results obtained showed an increase in the maximum dry density and a decrease in water content (Optimum Proctor characteristics) as the percentage of dune sand in the clay under study varied. However, for the same percentages of clay and lime, the results obtained indicated a decrease in the maximum dry density and an increase in water content (Optimum Proctor) according to the percentage of lime incorporated in clay. In addition, this article focused on the study of free swelling of the same mixtures of clay with the same percentages of sand and lime. Moreover, the evolution of the swelling pressure and hydraulic conductivity ofthe mixture of clay plus limewas also studied. The purpose of the present study is to develop and validate a local, low-cost and high-quality material that meets the Algerian regulations in force regarding the design of watertight barriers of waste disposal centers.

Keywords: Dune sand, lime, clay, hydraulic conductivity, passive barrier.

1. INTRODUCTION

Over the last few years, the technique of treating swelling soils with sand and lime has widely been used in the field of swelling stabilization, mainly for earthworks and embankment construction (road and motorway infrastructure, railways, airports, platforms, waste storage centers, etc.). The main purpose of using this technique is to dry out the soil, improve its maneuverability and, after placing the mixture (soil + sand or lime) and compaction, to achieve the desired objectives (stabilization of expansive soil, hydraulic conductivity, bearing capacity meeting fixed criteria, etc.). The installation of waste disposal centers requires the design of an impermeable layer of soil, called an engineered passive barrier, built at the bottom of the waste storage facility. Algerian regulations require the presence of a material with a maximum permeability of 10^{-9} m/s over one meter, in order to prevent any leaking leachate from landfills(Guyonnet et al., 2005). Many authors, such as (Daniel, 1984; Holtz, 1985; Cui et al., 2008; Lamara et al., 2014; Demdoum et al., 2016; Gueddouda et al., 2016 and Ören and Akar, 2016), studied the permeability of the passive layer of waste storage centers, using different types of soil.

In the same context, some studies related to the influence of sand addition on swelling are presented in the following:
- Komornit and Livnet (1969), cited by Gueddouda (2005), made mixtures of clay with sand additions at different rates. They found out that the addition of sand increases the maximum dry density and decreases the optimal water content for percentages of sand ranging from 10 to 30%.
- Didier (1972), cited by Hachichi (2006), studied the evolution of the behavior of montmorillonite while adding sand. He showed that adding 10% of sand was enough to reduce the swelling pressure by about 50%; he also indicated that a logarithmic relationship existed between the percentage of sand addition and swelling pressure.
- Bengraa in 2004, carried out research on swelling clays from the region of Oran (Algeria), by adding three types of sand (quarry sand, river sand and beach sand) at different rates varying from 10 to 40%. He succeeded in showing that when the percentage of sand increases, the swelling rate and pressure go down.
- In 2005, Kolay and Ramesh carried out a research work on two types of clay, *i.e.* kaolonite from Georgia and bentonite from CETCO - Illinois (USA), by adding sand at different percentages (10, 20, 30, 40 and 50%). They made observations similar to those reported by Bengraa who had reported that sand can also decrease the rate and pressure of swelling.
- Guedouda et al. (2007) studied the stabilization of three swelling clays, namely bentonite from Maghnia, clay from Laghouat and clay from Ain Améinas (Algeria), by adding dune sand, in addition to salt and sand. They found out that certain combinations showed a 90% reduction in the swelling rate.
- As for Amri et al. (2019), they worked on a type of swelling clay from the region of Media (Algeria) by adding dune sand at different rates (10, 20, 30 and 40%). They suggested that dune sand can also decrease the swelling rate of clay.

On the other hand, some authors have investigated the influence of lime addition on clay swelling. In this context, it is worth citing:
- Afès and Didier, in 2000 who carried out treatments of clay from Mila (Algeria) with lime at rates 3 % and 6%, for cure times of 7, 28 and 90 days.
- Bourokba Mrabent et al. in 2015 who successfully demonstrated that the addition of lime to clay from Mers El Kébir (Algeria), at rates between 2 and 8%, has an influence on the compaction parameters; this would also reduce the free swelling and swelling pressure.

Furthermore, it was found that the hydraulic conductivity of lime-treated soils can be strongly influenced by the initial parameters, such as the lime content, compaction conditions, and curing time. Note that the variation of permeability of treated soils remains difficult to explain due to the absence of a systematic analysis of the coupling between permeability and soil microstructure (Le Runigo, 2008). Generally, adding lime to a compacted soil with an optimal water content, under a given compaction energy, leads to a short-term increase in permeability (Brandl, 1981;McCallister, 1990;Nalbantoglu and Tuncer, 2001). This increase may be explained by the density drop observed following the lime addition, and consequently, after the particle rearrangement induced by the flocculation phenomenon. The magnitude of this

increase remains difficult to assess; it is around 2 to 3 orders of magnitude, according to (McCallister, 1990), but less than one order of magnitude according to Brandl (1981).
- Many authors (Brandl, 1981;McCallister, 1990;McCallister and Petry, 1992; Nalbantoglu and Tuncer, 2001) indicated that the permeability of lime-treated and compacted soils is closely linked to the amount of lime added.

For a given compaction condition, the permeability of the treated soil decreases when the treatment process is carried out with lime dosages greater than the Lime Fixing Point (LFP) of the treated soil.

Much research has been conducted on the permeability of lime-treated soils, while some researchers, such as Fossberg (1969)**,** reported a decrease in the coefficient of permeability of up to two orders of magnitude with the increase in lime content. On the other hand, others, such as Townsend and Klym, in 1966, mentioned a substantial growth in the coefficient of permeability of very clayey soils. These results suggest that the effect of lime on soil permeability depends on the nature and composition of natural soil(Alhassan, 2008).

This article intends to present a study on the influence of dune sand and lime additions on the swelling of clay intended for the design of engineered barriers meant for the construction of the bottoms of technical landfill centers. To do that, the clay from some deposits located in the region of Mraguen in the Wilaya of Adrar (southwestern Algeria) was utilized. Our choice fell on the lime from the Wilayas of Ghardaïa and Adrar, and on the dune sand thatis widely available in the southern part of Algeria. The scientific approach adopted consisted in carrying out the physicochemical and hydro-mechanical characterization of the mixtures obtained; this would certainly help to propose a formulation that meets regulatory criteria.

2. MATERIALS AND METHODS

2.1. Site location

Three basic materials, with different properties, were used in this study; two of them are local materials, namely clay soil and dune sand from the Wilaya (Province) ofAdrar. The expansive soil used is known as Mraguen clay; it comes from a deposit located a few kilometers north of the city of Adrar. The third material is lime from Ghardaïa, a city in central Algeria (Fig. 1). The clay was treated with sand and lime to stabilize and improve its geotechnical properties such as permeability which is a very important factor for the design ofwaste disposal centers.

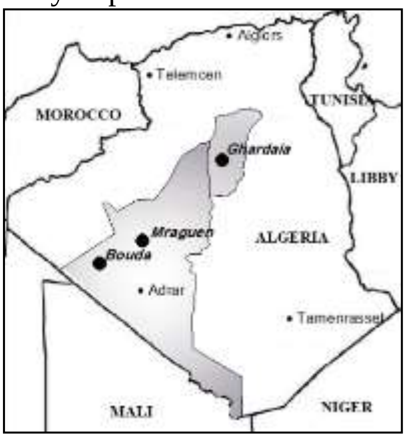

Fig. 1. Location of the studied materials

2.2. Clayey soil identification

The chemical analysis results of clay are summarized in (Table 1). It is worth noting that its main mineralogical constituents are silica (51.23%) and alumina (16.89%).

The physical properties of clay are shown in (Table 2). According to the Unified Soil Classification System (USCS), the clay from Adrar is classified among very plastic clay soils (CH); its activity (Ac) is normal, with 40% of its particles with size less than 2 µm. The total specific surface was deduced from the tests carried out on methylene blue (Vb) using the formula of Tran NgocLan (1981). The methylene *blue* absorption *value* for clay was determined according to Standard NFP 94-068. It was found that the specific surface was quite high; it was around 199.5m^2/g. This clay contained minerals close to calcium montmorillonite, according to the classification of Grim (1959), as cited in Smaida (2008). It is important to mention that the work of Williams and Donaldson, in 1980, had previously confirmed that Adrar clay has a very high swelling potential.

Table1: Chemical analysis of clayey soil.

Parameters	Denomination	Quantity (%)
Chemical	SiO_2	51.23
	TiO_2	1.40
	Al_2O_3	16.89
	Fe_2O_3	17.45
	CaO	0.06
	MgO	0.82
	Na_2O	0.24
	K_2O	4.10
	SO_3	0.04
	PH (18°)	8,04
	Loss on ignition	7,28

Table 2: Physical characteristics for clayey soil.

Standards	Dénomination	Measured Value
ASTM D-854	Density of solids grains (Gs)	2.65
ASTM D-4318	Liquid limit, LL (%)	70
ASTM D-4318	Plastic limit, PL (%)	25.49
/	Plasticity index (%) (PI = LL - PL)	44.51
ASTM D-4318	Shrinkage limit SL (%)	10.09
	Shrinkage index (%) (SI = LL - SL)	59.91
ASTM D-2217	Percentage of elements smaller than 2 µm, F2 (%)	40
/	Activity (PI/F2)	1.113
XP P94-047	Organic matter content OM (%)	0.086
ASTM D4373	Calcium carbonate content (%)	3.78
NF P94-068	Value of methylene blue (%)	9.5
/	Total specific surface area = 21VBS (m^2/g)	199.5
ASTM D-698	Dry density at MOP (KN/m^3)	17.40
/	Optimum water content (%)	14.33

2.3. Dune sand

The dune sand of Bouda, a locality a few kilometers west of the city of Adrarin the Saharan area of Algeria, is of yellow color. It is used as a clay stabilizer, at different percentages. The results of the dune sand identification tests are summarized in (Table 3). The dry particle-size analyses of the dune sand were carried out according to the standardized test NFP 18-560; these analyses made it possible to determine the *grain size distribution*. Moreover, this sand was found to be well graded, according to the soil classification of the French Central Laboratory for Bridges and Roads (LCPC); note also that this classification is based on the uniformity (Cu) and curvature (Cc) coefficients. The curve corresponding to sand (Sb) is quite uniform and spread out. In addition, the sand equivalent test was carried out according to Standard NFP 18-598. It should also be noted that, according to the Central Laboratory for Bridges and Roads classification, the dune sand from Bouda (Adrar) is clean. Note also that this sand can be silty or not, depending on its methylene *blue* absorption *value*. (Table 4) summarizes the chemical analysis results of this dune sand.

Table 3: Physical analysis of dune sand.

Standards	Denomination	Measured Value
	$\phi \leq 80$ µm	2
ASTM D-2217	$\phi \leq 2$ µm	0
NF P18-560	Uniformity coefficient Cu	4
NF P18-560	Curvature coefficient Cc	0.56
	Value of methylene blue (%)	0.2
	Total specific surface area = 21VBS (m^2/g)	4.2
NF P18-598	Visual sand equivalent (Esv)	39.99
NF P18-598	Piston sandeqivalent (Esp)	35.22
XP P94-047	Organic matter content OM (%)	0.043

Table 4: Chemical analysis of dune sand

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Parameters	Denomination	Quantity (%)
Chemical	SO_3	0.66
	Chlorures CL	0.03
	$CaCo_3$	0.44
	Conductivité électrique	2.81
	PH	8.67

2.4. Lime

Lime has the apparent volumetric weight value Mv_{app} = 1.7 g/cm^3 and absolute volumetric weight value Mv_{abs} = 2.34 g/cm^3, according to the standardized test NF P18-554-555.

2.5. Sample preparation

The mixtures (clay soil + sand) and (clay soil + lime) were prepared separately, at different percentages (2, 4, 6, 8, 10 and 12% by weight) of the added materials (sand and lime). For each mixture, the necessary amount of water was added to reach the *optimum moisture content* (OMC) for the *modified Proctor test*, according to Standard ASTM D698 – ASTM, 2000.

2.6. Soil compaction test

For each mixture, the Proctor optima were obtained graphically from the *peak* point of the compaction curves (Figures 2 and 3).

2.7. Free swelling test

The free swelling test was conducted on treated and untreated soils. Samples were reconstituted by the compaction test to the optimum Proctor characteristics. These cylindrical samples have a height H = 20 mm and diameter D = 50 mm (Chen, 1988;Serratrice and Soyez, 1996).
The free swelling tests were realized in a conventional oedometer according to Standard (ASTM D2435-96 – ASTM, 1996). The variation in height (G%) of the sample was determined according to the following formula (1):
$G\% = \Delta H / H_0$ (%) (1),

Where G is the height variation in the sample, H_0 is the initial height and H_f the final height after stabilization. Note also that $\Delta H = H_f - H_0$
The reduction in swelling potential is given by the relation below:

$$\frac{\Delta G}{G} = \frac{G0\% - Gp\%}{G0\%} \qquad (2)$$

Where G_0 is the swelling of untreated soil, G_p is the swelling of soil treated with dune sand or lime.

2.8. Swelling pressure test

The swelling pressure is that necessary to return the soil to its initial volume after it has swelled. Several methods have been reported in the past for measuring this pressure (Smaida, 2008). To do this, it was decided to use the constant volume swelling method according to Standard (ASTM D4546-90 – ASTM, 1990). In this case, the tendency of the sample to swell can be neutralized by the application of an increasing load as soon as the vertical displacement of the comparator reaches 1/100 mm. The value of the load applied when the sample is stabilized is the swelling pressure (Didier et al.1987, as cited by Chen, (1988); Serratrice and Soyez, 1996). The following relationship is used to determine the swelling pressure Pg. The samples were prepared following a procedure like the one used for the measurement of free swelling.

$$\frac{\Delta Pg}{Pg} = \frac{Pg0\% - Pgp\%}{Pg0\%} \qquad (3)$$

Here $Pg_0\%$ is the swelling pressure of untreated soil (kPa), and Pgp% is the swelling pressure of lime-treated soil (kPa).

2.9. Saturated hydraulic conductivity

The *Taylor square root of time* fitting *method* (1942), i.e. $\Delta h = f(\sqrt{T})$, allows estimating the value of the permeability (k) in terms of the two parameters, i.e. the oedometric modulus and consolidation coefficient, according to the following formula:

$$k = C_v . \gamma_w / E' \qquad (4)$$

Where C_v is the consolidation coefficient, E' is the oedometer modulus, and γ_w is the weight of water.

3. RESULTS AND DISCUSSION

3.1. Compaction tests

The results of the Proctor test conducted on soil treated with sand and lime are shown in (Fig. 2 and Fig. 3). The curve corresponding to these figures shows the maximum dry density (MDD) and the optimum moisture content (OMC) according to the percentages of sand and lime additions. For the mixture of Mraguen clay with sand, it was found that when the percentage of sand increased from 2 to 12%, the maximum dry density (MDD) increased from 1.73 to 1.85 g/cm^3 and the optimum moisture content (OMC) dropped from 14.33 to 13.41%. The optimum moisture content (OMC) decrease observed can be justified by the decline in the specific surface of the mixture due to the incorporation of sand particles into clay. This decline is attributed to the absorption of water by the added sand. A similar behavior was observed by other researchers while studying the effect of sand addition on the Proctor parameters of clay soils Bell (1996); Bengraa et al. (2009); Bozbey and Garaisayev (2009); Lamara et al. (2014); Kolay and Ramesh (2015); Elmashad (2018); Amri et al. (2019). Conversely, for the mixture of Mraguen clay and lime, it was reported that when the percentage of lime increased from 2 to 12%, the maximum dry density (MDD) decreased from 1.73 to 1.61g/cm^3, and the optimum moisture content (*OMC*) increased from 14.33 to 21.69%. Similar results were obtained by several other researchers (Afès and Didier, 2000; Zhang and Cao, 2002; Djedid et al., 2003). The results obtained may be explained by the maximum dry density decline which was due to the rearrangement of clay particles caused by the phenomenon of flocculation and agglomeration; on the other hand, the increase in the optimal moisture content was due to the increasing water needthat was necessary for hydration as well as to the pozzolanic reaction (Ola, 1977; Bell, 1996;Khattab and Fleureau, 2007 ; Khattab et al., 2008, and Bozbey etGaraisayev, 2009). The pozzolanic reactions between clay particles and lime in soils are responsible for the optimal moisture content (OMC) increase as this process enhances the soil affinity for water. In the same context, Bell, in 1996) reported the same findings, stating that the decrease in the dry density of lime-treated soil is generally attributed to flocculation phenomenon, whatever the type of soil studied; note also that this is generally accompanied by an increase in the optimal moisture content. The magnitude of change in these two parameters is linked to the type of soil treated.

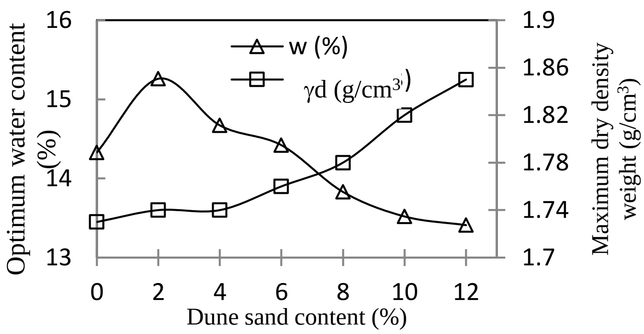

Fig. 2. Variation of maximum dry density and the optimum water content versus dune sand.

PONTE
Vol. 76 No. 2, 2020 Florence, Italy
*ISSN:*0032-423X*E-ISSN:*0032-6356 International Journal of Sciences and Research

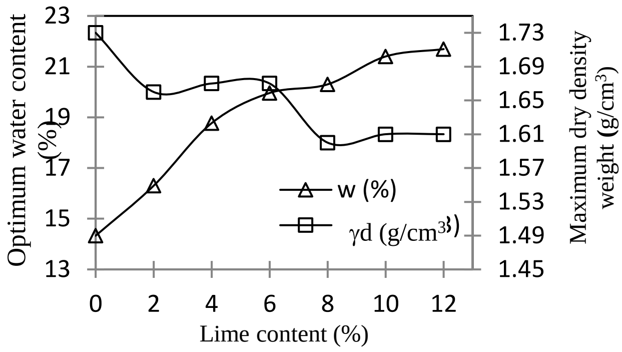

Fig. 3. Variation of maximum dry density and the optimum water content versus lime.

Fig. 4 illustrates the relative variation of the maximum dry density (MDD) of soil as a function of the percentage of sand and lime additions. An increase in dry density was noted as a function of the percentage of added sand; this increase was certainly due to the filling of inter-grain voids in sand with fine and cohesive particles (Elmashad, 2018).Nevertheless, a decrease was noted in the maximum dry density for the mixture of clay and lime; this was due to the phenomena of flocculation and agglomeration.

On the other hand, (Fig. 5) displays the relative variation of the optimal moisture content (OMC) of soil as a function of the percentage of sand and lime additions. A slight decrease in the OMC was noticed for the mixture of clay and sand; this was certainly caused by the reduction in the specific surface area of the mixture as a result of the incorporation of sand particles into clay. Conversely to mixtures (clay + sand), it was noted that the optimal moisture content value increased as the lime dosage went up, which is justified, on the one hand, by the increasing water need that was necessary for the dissociation of lime in ions, and on the other hand, by the pozzolanic reaction.

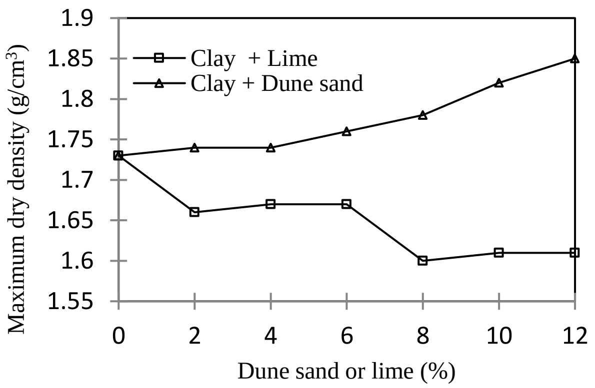

Fig.4. Variation of maximum dry density versus percentage dune sand or lime

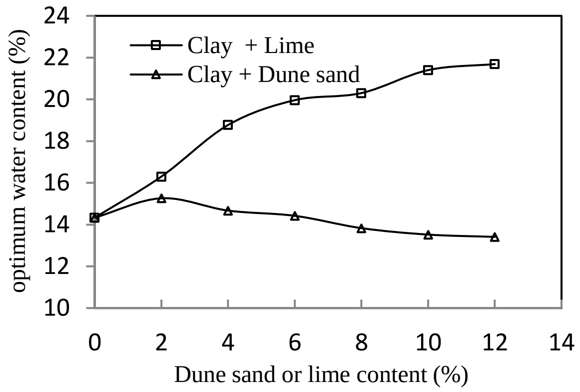

Fig. 5. Variation of the optimum water content versus dune sand or lime

3.2. Free swelling tests

The curves of (Fig. 6 and Fig. 7) represent the relative variation of the height H as a function of the logarithm of time *[ΔH / H = f (log (t))]*. There are two swelling phases; the first one is the primary swelling phase that takes place very early and ends with an inflection point, thus allowing for a change in the shape of the curve, and then the secondary swelling phase which is characterized by the linear portion of the curve(Holtz and Kovacs, 1991).

Regarding Figure 6, the shape of the curve representing the evolution of free swelling over time is the same for all the (clay + sand) mixtures. However, it was noted that the higher the percentage of sand, the smaller the swelling potential. This can be explained as follows: For a low percentage of addition (2%), the sand particles get dispersed through the clay structure. It is worth knowing that the effect of adding sand on the clayey soil structure is small and therefore the reduction in swelling is not significant. Subsequently, with the increase in the rate of addition (from 4 to 12%), the amount of sand added leads to the formation of a quite important number of voids inside the soil structure, which allows absorbing the volume changes caused by clay particles inside the structure. This feature leads to a reduction in the swelling potential from 29 to 15.8%. These same comments were also made by Amri et al.(2019); Kolay and Ramesh (2015) and Demdoum et al.(2016).

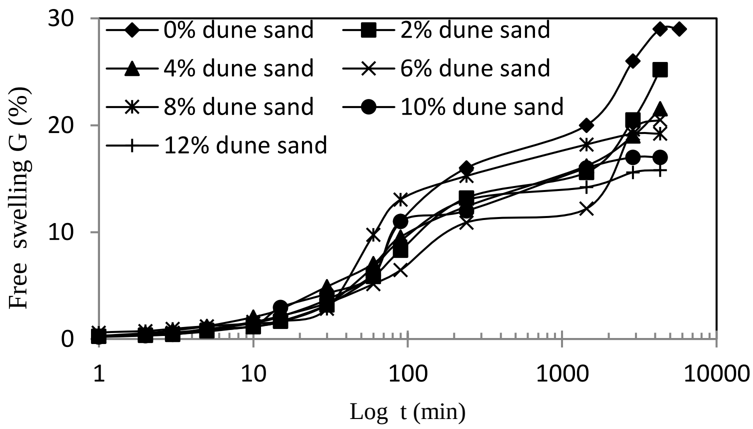

Fig. 6. Free swelling evolution of clay with dune sand mixture versus logarithm of time

*ISSN:*0032-423X*E-ISSN:*0032-6356

As for (Fig. 7), it shows the graphical representation of the evolution of the swelling rate as a function of time, for the clay + lime mixture. The shape of the curve is the same as that of the clay + sand mixture. One may easily note that the higher the lime addition rate, the lower the swelling potential (Afès and Didier, 2000; Djedid, 2005; Bourokba Mrabent et al., 2015). Indeed, it was found that the swelling potential dropped from 29 to 13.25%.

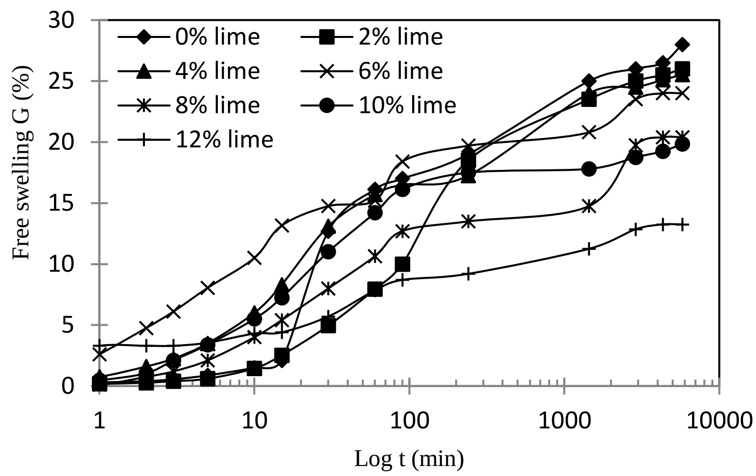

Fig. 7. Free swelling evolution of clay with lime mixture versus logarithm of time.

On the other hand, it was revealed that for a high lime addition percentage (12%), free swelling decreases by approximately 54.31% with respect to total swelling. However, for a sand percentage of 12%, the reduction in free swelling was around 45.51% (Fig. 8 and Fig. 9).

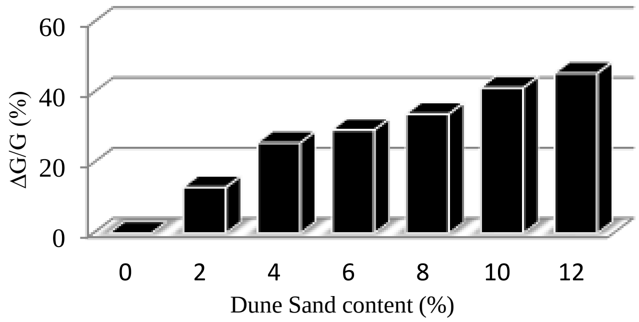

Fig. 8. Improvement in swelling potential due to mixing the clay with dune sand.

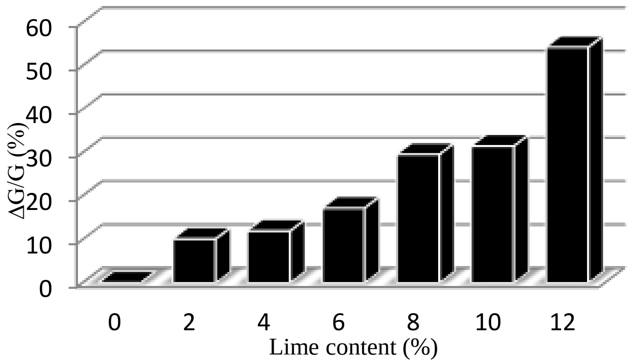

Fig. 9. Improvement in swelling potential due to mixing the clay with lime.

The results of the variation in free swelling potential of the different mixtures as a function of the rate of sand and lime additions are grouped in (Fig. 10). It is worth noting that lime and sand additions lead to lower values of swelling potential. This trend turned out to be proportional to the percentages of lime and sand added. It should also be mentioned that for a small percentage of lime and sand (2%), the swelling potential decrease was nearly similar for both. However, for percentages of 4 and 6% of lime, the reduction in the swelling potential was smaller than that of sand.

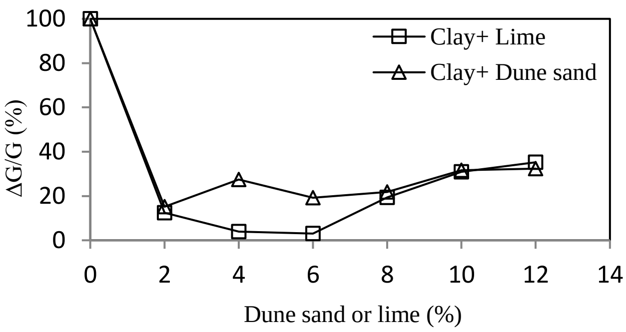

Fig. 10. Evolution in swelling potential versus dune sand or lime.

3.3. Swelling pressure test

The swelling pressure is defined as that pressure that is required to keep the fully flooded soil sample at its original position. One may easily notice that the swelling of clay is very high. The swelling pressure in this clay should also be very high as it is directly proportional to the swell index of soil. The results of the swelling pressure tests for this clay as a function of the percentage of lime added are presented in (Fig. 11 and Table 5).

Fig. 11 clearly shows that the swelling pressure decreases as the amount of lime rises. This is attributed to the reduction in adsorption, which is in agreement with the results of several researchers like Afès and Didier, in 2000, Khattab, in 2002, Al-Mukhtar etal., in 2010, Bourokba Mrabent et al., 2015. It should be mentioned that the gradual change in the swelling pressure is caused by the pozzolanic reaction between lime and the clay particles, which leads to a significant decrease in the swelling pressure. This decline is due to the short and long-term effects of flocculation and agglomeration. These findings allow concluding that these effects of flocculation and agglomeration are the result of the ion exchange occurring at the surface.

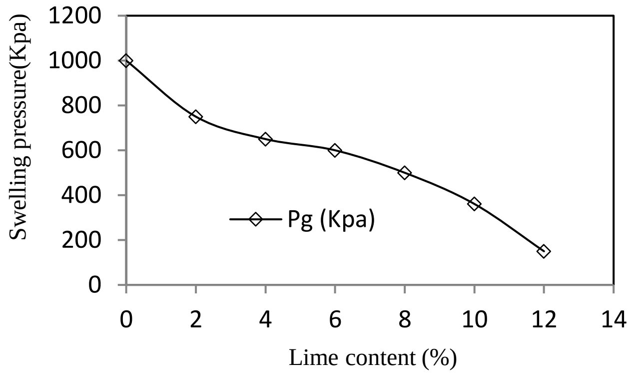

Fig. 11. Percentage of lime versus swelling pressure.

Table5 : Variation de la pression de gonflement en fonction du pourcentage de la chaux.

A + % C	Pg (Kpa)	ΔPg/Pg(%)
A + 0% C	1000	-
A + 2% C	750	25
A + 4% C	650	35
A + 6% C	600	40
A + 8% C	500	50
A+10%C	361	63.8
A+12% C	150	85

3.4. Permeability coefficient

Fig. 12 shows the effect of lime on the consolidation coefficient of untreated and treated clay deduced from the method of Taylor. It is useful to know that the consolidation coefficient values for most fine soils are between 10^{-4} and 10^{-3} cm^2/s Sibille, (2018).Note also that the consolidation coefficient of Mraguen clay (10^{-3} cm^2/s) is within this interval. Fig. 12 clearly indicates that the consolidation coefficient (Cv) increases slightly with the amount of lime added to clay, which is in agreement with the results reported by several researchers (Nguyen, 2015; DjelloulR, 2018). It is also noted that the increase in the consolidation coefficient is linked to the cation exchange and flocculation / agglomeration processes, which is mainly attributed to the reaction between lime and clay (Herzog and Mitchell, 1963; Nalbantoglu and Tuncer, 2001).

Fig. 13 presents the results related to the variation of the hydraulic conductivity of the mixtures of untreated and treated clay with different percentages of lime for the maximum vertical stress of 16 bars. A slight permeability increase was observed as the percentage of lime went up. Beyond the amount of 10% of lime, a sharp drop in permeability, from $9.41.10^{-9}$ to $0.12.10^{-9}$ m/s, was noted when the percentage of lime added passed from 2 to 12%. Regarding the effect of the added amount of lime, all of Brandl (1981), McCallister (1990) and Nalbantoglu and Tuncer (2001), indicated that the permeability of lime-treated soil increased up to a certain value corresponding to the Lime Fixation Point (LFP). Note that the permeability remains slightly stable beyond this quantity. These authors assume that for lime dosages lower than the lime fixation point, the increase in permeability is due to the dry density decline in the compacted treated soil. It is worth mentioning that for lime dosages higher than the LFP, the density reductions are offset by the significant precipitation of cementitious products, thus reducing the circulation of water in soil and therefore decreasing the permeability(Le Runigo, 2008; Nguyen, 2015). In addition, according to these authors (McCallister, 1990; McCallister and Petry, 1992), the permeability reduction phase depends on the increasing formation of cementitious products during the percolation time, since these products block the pores in the material. Similarly,(Al-kiki et al. (2008)suggested that for a hardening period exceeding 7 days, the permeability of the stabilized soil decreases over time.

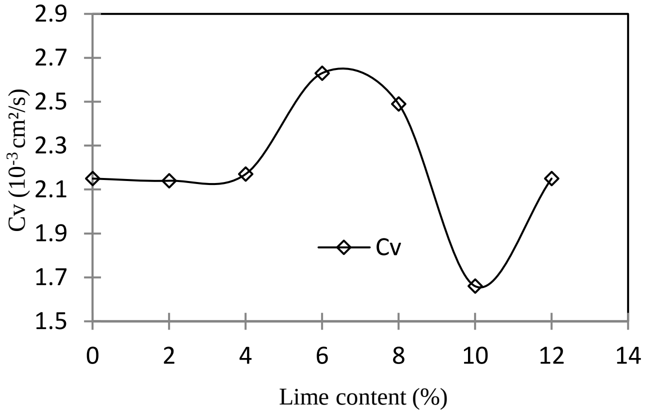

Fig. 12. Percentage of lime versus cofficient of consolidation.

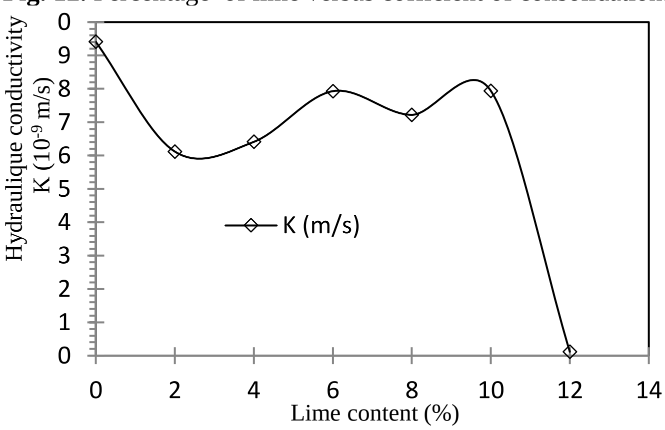

Fig. 13. Hydraulic conductivity of clay-lime mixture, as a function the percentage of lime

4 – CONCLUSIONS

The present article is of major importance as it provides a methodology of local materials recovery from the region of Adrar to be used in the design of waste disposal centers. Several tests were performed to determine the influence of dune sand and lime additions to swelling clay on several parameters, such as compaction, swelling potential, swelling pressure, and hydraulic conductivity. The following conclusions could be drawn:
- When the percentage of sand increased from 2 to 12%, the maximum dry density also increased but the optimal moisture content decreased. This optimal moisture content decline can be justified by the reduction in the specific surface area of the mixture due to the incorporation of sand particles into clay. This reduction is related to the absorption of water by the added sand. On the other hand, it was observed that for the mixture (clay + lime) when the amount of lime increases, the maximum dry density decreases and the optimal water content increases. Note that the reduction in the maximum dry density, which is due to the reorganization of the clay particles, is caused by the phenomenon of flocculation and agglomeration, while the increase in the optimal water content is due to the increasing water needs for adequate hydration; this maximum dry density decline is also attributed to the pozzolanic reaction.
- The higher the percentage of sand, the lower the swelling potential; this can be explained as follows:
* The amount of sand added leads to the creation of voids with quite important volumes inside the soil structure. Consequently, variations in volume due to clay particles are observed within the structure, which induces a swelling potential decline.
* A similar remark can be made for the mixture of (clay + lime); note that the larger the amount of added lime, the lower the swelling potential of soil. The reduction in swelling of the mixture with lime is more important than that of the mixture with sand.This allowed us to follow the other tests on the lime mixture
- The swelling pressure decreases as the percentage of lime increases because adsorption goes down. The gradual change in swelling pressure is attributed to the pozzolanic reaction between lime and clay particles, which results in a significantly reduced swelling pressure. Note that this decrease is due to its immediate and long-term effects, immediately, the effects are due to flocculation and agglomeration resulting from the ion exchange occurring at the surface.
- The impact of the amount of added lime on the consolidation coefficient Cv, deduced by the Taylor method, increases slightly. This increase is related to the cation exchange and flocculation / agglomeration processes that result from the reaction between lime and clay.
- The variation in the hydraulic conductivity of clay mixtures with different percentages of lime, for the maximum vertical stress of 16 bars, indicates a slight permeability increase as the lime content rises. Beyond the 10% lime percentage, the permeability drops suddenly. For example, for 12% of lime, the permeability value goes down to $0.12.10^{-9}$ m/s. This result perfectly meets the conditions required by the regulations. This permeability decline may be explained by the density decrease which is balanced by the formation of cementitious products after the addition of lime. This would reduce the circulation of water through soil (Le Runigo, 2008).

Therefore, the above-mentioned results confirm that the 12% lime percentage can ensure the waterproofing of soil, and provides an adequate mechanical behavior to the watertight walls of waste disposal centers. Consequently, this economical local material combining clay and lime can be recommended for the design of waste storage facilities.

ACKNOWLEDGEMENTS

All my thanks go to the staff of the Geotechnical Laboratories at the Universities of Adrar and Oran (USTO) for their kind help in conducting laboratory tests, and more particularly Pr Abdelkader HACHICHI and Mr. Akram HAMAL.

I would like to thank Pr Aboubekr Nabil and Dr Derfouf Mounir of EOLE laboratory (Eau et Ouvrage dans Leur Environnement) for their contribution in the realization of the experimental part of this research.

REFERENCES

ASTM,1990. D4546-90. Standard test methods for one-dimensional swell or collapse of soils. Philadelphia, PA.
ASTM, 1996. D-2435. Standard Test Methods for one-dimensional consolidation properties of soils. Annual book of ASTM Standards, vol 04.08. Easton, PA.
ASTM, 1996. D-4373. Standard Test Method for Calcium Carbonate Content of Soils. ASTM International, West Conshohocken, PA.
ASTM, 1998. D-2217. Standard test method for wet preparation of soil samples for particle size analysis and determination of soil constants. Annual Book of ASTM Standards, vol. 04.08.Easton, PA.
ASTM, 2000. D-4318. Standard test method for liquid limit, plastic limit and plasticity index of soils. Annual Book of ASTM Standards, vol. 04.08. Easton, PA.
ASTM, 2000. D-698 Standard test method for laboratory compaction characteristics of soil using standard effort. Annual Book of ASTM Standards, vol. 04.08. Easton, PA.
ASTM, 2002. D-854 Standard test method for specific gravity of soil solids by water pycnometer. Annual Book of ASTM Standards, vol. 04.08. Easton, PA.
Afès, M., Didier, G., 2000. Stabilisation des sols gonflants: Cas d'une argile en provenance de Mila (Algérie). Bull. Eng. Geol. Environ. 59, 75–83. https://doi.org/10.1007/s100649900022.
Al-kiki, I.M.A., Al-juari, K.A.K., Dr.Khattab, S.A.A., 2008. Strength, Durability And Hydraulic Properties Of Clayey Soil Stabilized With Lime And Industrial Waste Lime. Al-Rafidain Eng. 16, 102–116. https://doi.org/10.33899 / rengj.2008.44026.
Al-Mukhtar, M., Lasledj, A., Alcover, J.F., 2010. Behaviour and mineralogy changes in lime-treated expansive soil at 20°C. Appl. Clay Sci. 50, 191–198. https://doi.org/10.1016/j.clay.2010.07.023.
Alhassan, M., 2008. permeability of lateritic soil treated with lime and Rice Husk Ash. AU J.T 12, 115–120. https://doi.org/http://www.aulibrary.au.edu/multim1/ABAC_Pub/Au-Journal-of-Technology/v12-n2-7.pdf.
Amri, S., Akchiche, M., Bennabi, A., Hamzaoui, R., 2019. Geotechnical and mineralogical properties of treated clayey soil with dune sand Salima Amri, Mustapha Akchiche, Abdelkrim Bennabi, Rabah Hamzaoui. J. African Earth Sci. https://doi.org/10.1016/j.jafrearsci.2019.01.010.
Bell, F.G., 1996. Lime stabilization of clay minerals and soils. Eng. Geol. 42, 223–237. https://doi.org/10.1016/0013-7952(96)00028-2.
Bengraa, L., 2004. Contribution à l'étude de la stabilisation du gonflement par ajout de sable, application aux sols d'Oran. Magistra thesis, U.S.T. Oran University, Algeria.
Bengraa, L., Hachichi, A., Bourokba, S.A., 2009. Comportement mécanique d'une argile gonflante traitée par ajout de sable, in: Premier Symposium Méditerranéen de Géoengineering, Alger, Algeria. Algeria.
Bourokba Mrabent, S.A., Hachichi, A., Souli, H., Taibi, S., Fleureau, J.M., 2015. Effect of lime on

some physical parameters of a natural expansive clay from Algeria. Eur. J. Environ. Civ. Eng. 21, 108–125. https://doi.org/10.1080/19648189.2015.1093963.
Bozbey, I., Garaisayev, S., 2009. Effects of soil pulverization quality on lime stabilization of an expansive clay. Environ. Earth Sci. 60, 1137–1151. https://doi.org/10.1007/s12665-009-0256-5.
Brandl, H., 1981. Alteration of soil parameters by stabilization with lime., in: Proceedings of the 10th International Conference on Soil Mechanics and Foundation Engineering, Volume 3, Stockholm. Stockholm, Suède, pp. 587–595. https://doi.org/https://trid.trd.org/view/187515.
Chen, F.H., 1988. Foundations on expansive soils.Developments in Geotechnical Engineering, Elsevier P. ed. Amsterdam.
Cui, Y.J., Tang, A.M., Loiseau, C., Delage, P., 2008. Determining the unsaturated hydraulic conductivity of a compacted sand-bentonite mixture under constant-volume and free-swell conditions. Phys. Chem. Earth 33, 462–471. https://doi.org/10.1016/j.pce.2008.10.017.
Daniel, D.E., 1984. Predicting hydraulic conductivity of clay liners. J. Geotech. Eng. 110, 285–300. https://doi.org/https://doi.org/10.1061/(ASCE)0733-9410(1984)110:2(285).
Demdoum, A., Gueddouda, M.K., Goual, I., Benabed, B., 2016. Geotechnical characterization of geomaterial blends with Bentonite of Maghnia for use as landfill liners A. J. Mater. Process. Environ. 4, 48–54. https://doi.org/https://www.researchgate.net/profile.
Djedid, A., 2005. L'identification des sols gonflants : pour une démarche unifiée, in: Pro. 2ème Journée d'Etudes Sur Les Sols Gonflants, 13 Novembre. Université de Tlemcen, Algérie.
Djedid, A., Aissa Mamoune, S.M., Bekkouche, A., 2003. Comment reconnaître un sol expansif, in: Pro. Séminaire National de Génie Civil, 28-29Janvier. Oran Algeria.
Djelloul.R, 2018. Influence de l'ajout de chaux et de ciment sur les proprietes physico-mecaniques d'une argile naturelle de la region d'oran en vue de sa valorisation en construction routiere. PhD thesis, Oran Mohamed Boudiaf, Algeria.
Elmashad, M. eldin M.A., 2018. Improving the geotechnical behavior of sand through cohesive admixtures. Water Sci. 32, 67–78. https://doi.org/10.1016/j.wsj.2018.03.001.
Fossberg, P.E., 1969. Some Fundamental Engineering Properties of a Lime - stabilized Clay. Libr. Int. Soc. Soil Mech. Geotech. Eng. 221–225. https://doi.org/10.1007/978-3-319-73568-9_174.
Gueddouda, M.K., 2005. Stabilisation des argiles gonflantes par ajout de sable de dunes ; Cas : Région de Laghouat. Magistra thesis, Université de Tlemcen, Algeria.
Gueddouda, M.K., Goual, I., Benabed, B., Taibi, S., Aboubekr, N., 2016. Hydraulic properties of dune sand–bentonite mixtures of insulation barriers for hazardous waste facilities. J. Rock Mech. Geotech. Eng. 8, 541–550. https://doi.org/10.1016/j.jrmge.2016.02.003.
Guedouda, M.., Lamara, M., Benabed, B., Goual, I., 2007. Effet du mode de compactage sur les paramètres de gonflement des sols expansifs. Algérie Equipement. N°43, 11–16. https://doi.org/http://www.entp.edu.dz/revue/files/article/43/article 3.pdf.
Guyonnet, D., Gaucher, E., Gaboriau, H., Pons, C.H., Clinard, C., Norotte, V., Didier, G., 2005. Geosynthetic clay liner interaction with leachate: Correlation between permeability, microstructure, and surface chemistry. J. Geotech. Geoenvironmental Eng. 131, 740–749. https://doi.org/10.1061/(ASCE)1090-0241(2005)131:6(740).
Hachichi, A., 2006. Etude du comportement hydromécanique et de la stabilisation des sols gonflants de la région d'Oran. PhD thesis, Université d'Oran Algeria.
Herzog, A., Mitchell, J.K., 1963. Reactions accompanying stabilization of clay with cement. Highw. Res. Rec. 36, 146–171. https://doi.org/http://onlinepubs.trb.org/Onlinepubs/hrr/1963/36/36-008.pdf.
Holtz, R., Kovacs, W., 1991. An introduction to geotechnical engineering, 2nd ed. Montréal, Canada.
Holtz, W.G., 1985. Discussion of "Predicting hydraulic conductivity of clay liners" by David E. Daniel. J. Geotech. Eng. 111, 1457–1459. https://doi.org/10.1061/(ASCE)0733-9410(1985)111:12(1457.2).
Khattab, A.S., 2002. Etude multi-échelles d'un sol argileux plastique traité à la chaux. PhD thesis, Université d'Orleans, France.

Khattab, S.A.A., Fleureau, J., 2007. Long-Term Stability Characteristics of a Lime-Treated Plastic Soil. J. Mater. Civ. Eng. ASCE 19, 358–366. https://doi.org/10.1061/(ASCE)0899-1561(2007)19:4(358).

Kolay, P.K., Ramesh, K.C., 2015. Reduction of Expansive Index, Swelling and Compression Behavior of Kaolinite and Bentonite Clay with Sand and Class C Fly Ash. Geotech. Geol. Eng. 34, 87–101. https://doi.org/10.1007/s10706-015-9930-4.

Lamara, M., Chiker, T., Amara, S., Gueddouda, M.K., 2014. Protection de L'environement à travers la valorisation de sable de dune dans les régions arides, in: 1er Colloque International CBE, 27-28 Mai. Jijel Algeria, pp. 1–10.

Le Runigo, B., 2008. Durability of the lime-treated Jossigny Silt under different hydraulic stresses: Assessment of the mechanical, hydraulic, microstructural behaviour. Thèse Dr. École Cent. Nantes - Fr. University of Nante, France.

McCallister, L.D., 1990. The effects of leaching on lime-treated expansive clays. Thesis from university of Texas, Arlington.

McCallister, L.D., Petry, T.M., 1992. Leach tests on lime-treated clays, Geotechnical Testing Journal. https://doi.org/https://doi.org/10.1520/GTJ10232J.

Nalbantoglu, Z., Tuncer, E.R., 2001. Compressibility and hydraulic conductivity of a chemically treated expansive clay. Can. Geotech. J. 38, 154–160. https://doi.org/10.1139/cgj-38-1-154.

Nguyen, T.-T.-H., 2015. Stabilisation des sols traités à la chaux et leur comportement au gel. PhD thesis, Université de Paris-Est.

Ola, S.A., 1977. The potentials of lime stabilization of lateritic soils. Eng. Geol. 11, 305–317. https://doi.org/10.1016/0013-7952(77)90036-9.

Ören, A.H., Akar, R.Ç., 2016. Swelling and hydraulic conductivity of bentonites permeated with landfill leachates. Appl. Clay Sci. 142, 81–89. https://doi.org/10.1016/j.clay.2016.09.029.

Serratrice, J.F., Soyez, B., 1996. Les essais de gonflement. Bull. des Lab. des Ponts Chaussees 4082, 65–85.

Sibille, L., 2018. Bases de la Géotechnique Module MXG4 IUT Génie Civil et Construction Durable, in: Hal.Archives-Ouvertes. 4 Jul 2018, France, pp. 1–57.

https://hal.archives-ouvertes.fr/cel-01784530v1 Smaida, A., 2008. Stabilisation des argiles gonflantes, l'effet de la chaux et du ciment sur les propriétés physico-mécaniques. PhD thesis, Ecole Nationale Polytechnique d'Oran,Algeria.

Townsend, D.L., Klym, T.W., 1966. Durability of Lime-Stabilized Soil. Highw. Res. Rec. 25–41. https://doi.org/http://onlinepubs.trb.org/Onlinepubs/hrr/1966/139/139-003.pdf.

Williams, A.B., Donaldson, G.W., 1980. Developements related to building on expansive soils in South Africa, in: . . Proc. 4th Int. Conf. on Expansive Soils. pp. 834–844.

Zhang, J.R., Cao, X., 2002. Stabilization of expansive soil by lime and fly ash. J. Wuhan Univ. Technol. Mater. Sci. Ed. 17, 73–77. https://doi.org/10.1007/bf02838423.