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Effects of hydraulic binders on swelling parameters and shear strength on an expansive clay

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Article

Keywords
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Abstract

The phenomenon of soil swelling is primarily caused by climatic conditions such as drought and rain, as well as the mineralogical composition of soils. These factors strongly influence the shrinkage–swelling behavior of clays, which can cause significant damage to structures. Several techniques exist for the design and stabilization of expansive soils. This study presents a chemical stabilization approach by adding low percentages (2–8%) of lime and cement to a swelling clay from southern Algeria (Laghouat clay). Initially, materials were characterized using standard geotechnical tests, supplemented by chemical and mineralogical analyses. Based on identification tests, an indirect method to estimate the soil's swelling potential was developed and validated by direct measurements of swelling parameters. Subsequently, various mixes were tested to evaluate the effect on shear strength. The results indicate a significant reduction in swelling potential, free swelling, and plasticity index (approximately 80%, 90%, and 90%, respectively), along with a marked increase in cohesion from 111 kPa to 313 kPa (about threefold). These findings confirm that low percentages of lime and cement are effective for stabilizing expansive soils while improving their mechanical properties.

1. Introduction

The stability of structures is one of the major issues that engineers often face. Among the most common causes of structural instability worldwide, and in Algeria in particular, the phenomenon of shrinkage–swelling of the subgrade soil is undoubtedly one of the most dangerous and, paradoxically, one of the least understood (Muntohar, 2003; Smaida et al., 2021). Consequently, designers must take into account the effects induced by this phenomenon.

The shrinkage–swelling phenomenon can cause significant disruptions, such as settlement or heaving, between various points in structures and in pavements (Chen, 1988; Steinberg, 1998; Nelson & Miller, 1992; Muntohar, 2003; Akbulut et al., 2007; Cokca et al., 2009; Smaida et al., 2021; Habal et al., 2024; Satyanaga et al., 2024). Their significance obviously depends on the design of foundations and structures of the concerned buildings. The swelling nature of certain clays is primarily linked to their mineralogical composition. Other factors, such as soil structure, density, and initial water content, can significantly affect the swelling pressure or deformation of these clays (Chen, 1988; Steinberg, 1998; Nelson & Miller, 1992; Akbulut et al., 2007; Cokca et al., 2009; Dewangga et al., 2025).

These phenomena are more pronounced when they occur in regions with significant climatic variations, particularly with strong evaporation gradients and seasonal humidity deficits. During periods of drought, the decrease in soil moisture levels can lead to differential subsidence that can damage constructions. The soil may not return to its original volume after the wetting period, and cracks may not close completely (Chen, 1988; Steinberg, 1998; Nelson & Miller, 1992; Akbulut et al., 2007; Cokca et al., 2009; Habal et al., 2024). It is common for the extent of disturbances recorded to intensify after each new drying–wetting cycle. In most cases, buildings cannot tolerate such movements without damage, and cracks with several centimeters of opening can appear. Furthermore, distortions of doors and windows, detachment between adjoining buildings, or even ruptures of buried pipes can be observed (Derriche & Kebaili, 1998; Hachichi & Fleureau, 1999; Lamara et al., 2006; Habal et al., 2024; Sagitaningrum et al., 2025).

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In addition, the variation of the humidity rate in expansive soils has a great influence on their mechanical behavior, such as structural changes and reduction of shear strength (Satyanaga et al., 2024; Loskutova et al., 2025). In Algeria, this phenomenon, which is still poorly understood, affects hundreds of square kilometers across the territory. The damage caused by soil swelling to buildings and light structures is considerable, as observed in southern Algeria (Derriche & Kebaili, 1998), western Algeria (Hachichi & Fleureau, 1999), and in Laghouat (southern Algeria – Amar Tledji University of Laghouat and life base pumping station No. 5) (Lamara et al., 2006).

A number of solutions have been proposed to address this problem. These must be capable of minimizing the pressures developed during soil saturation. Among these solutions, stabilization techniques generally use chemical stabilization (Gueddouda et al., 2011; Zhao et al., 2014; Radhakrishnan et al., 2017; Moghal et al., 2020; Smaida et al., 2021; Satyanaga et al., 2024), stabilization by binders (slag, ash, lime, cement, fly ash, and blast furnace slag) (Gueddouda et al., 2011; Schanz & El Sawy, 2015; Mukherjee & Mishra, 2017; Bekhiti et al., 2019; Smaida et al., 2021; Habal et al., 2024; Abeysinghe et al., 2025; Li et al., 2025; Loskutova et al., 2025), stabilization by compaction (Attom, 1997; Lu et al., 2019), stabilization by fibers (propylene, nylon, and palmyra fibers) (Puppala & Musenda, 2000; Al-Akhras et al., 2008), stabilization using recycled tires (Belabdelouahab & Trouzine, 2014; Mukherjee & Mishra, 2017; Bekhiti et al., 2019), and stabilization using biopolymers (Moghal et al., 2024), and advanced techniques such as carbon nanotubes for slope stabilization of silty soils (Ahmadi et al., 2024) or GeoBarrier systems using steel slag and recycled concrete (Abishev et al., 2025).

Table 1. Physical properties of clay used.

Properties	Value
Liquid limit *LL* (%)	33
Plastic limit *PL* (%)	16.7
Plasticity index *PI* (%)	16.3
Shrinkage limit *SL* (%)	17.07
Absolute density (g/cm^3)	2.66
$\Phi \leq 80\mu m$ (%)	59
$\Phi \leq 2\mu m$ (%)	32.33
$\Phi \leq 1\mu m$ (%)	31.69
Maximal dry density γ_{dmax} (g/cm^3)	1.78
Optimal water content W_{OPN} (%)	15.2
Blue value *VB* (for 100 g)	9
Specific surface area *SSA* (m^2/g)	189

The present study contributes to chemical stabilization by adding lime and cement to a clay from southern Algeria. However, few studies have systematically examined the effectiveness of low-percentage lime–cement combinations on Algerian expansive clays, comparing both indirect and direct methods for assessing swelling while taking into account the local mineralogical characteristics. This analysis is carried out first through the estimation of swelling potential using indirect measurements according to existing classifications, and then through direct measurements of swelling parameters (potential and swelling pressure). The study focuses on the effects of different stabilization techniques on swelling parameters and shear strength, providing insights specific to the local clay mineralogy.

2. Materials and methods

2.1 Materials

2.1.1 Laghouat clay

This soil is from the Laghouat region (Pumping Station Base Camp, No. 5), approximately 20 km northwest of the city. This clay was sampled at a depth of 1.5 m. The XRD spectrum shows the presence of Illite-kaolinite mixtures, along with calcite and quartz. The particle size analysis is performed using two successive and complementary processes: underwater sieving (wet sieving) supplemented by sedimentometry for particles smaller than 80 µm (the standard NF P 94-057, AFNOR, 1992). The results of the particle size analysis show that 59% of the entire sample passes through the 80 µm sieve and that approximately 33% of the elements are smaller than 2 µm. According to the Casagrande abacus, our clay is classified among the medium-clayey, low-plastic soils. The physical characteristics of clay are grouped in Table 1 and Table 2 presents its chemical composition. The X-Ray Diffraction (XRD) of the studied soil is given in Figure 1. The Proctor curve and the grading curve of this soil as shown in Figures 2 and 3, respectively. The corrected activity (*Ac*) of Seed et al. (1962) is given by the following formula (Equation 1):

$$A_c = \frac{PI}{C_2 - n} \tag{1}$$

with $n = 5$ in the case of natural soils, and n=10 for reconstituted soils, C_2 is the particle content less than 2 µm, and *PI* is the plasticity index.

Table 2. Chemical composition of clay.

SiO_2	Al_2O_3	$CaCO_3$	NaCl	Fe_2O_3	SO_4	H_2O	CO_2
50.95%	5.25%	23.24%	0.23%	2.13%	1.85%	11.15%	5.90%

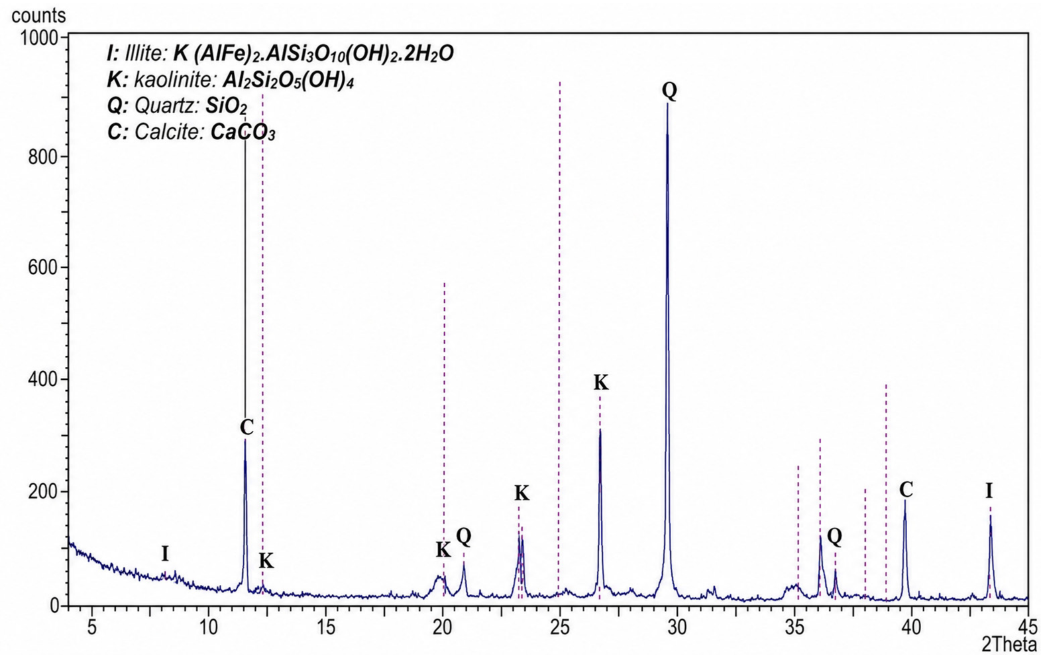

Figure 1. Mineralogical analysis of Laghouat clay.

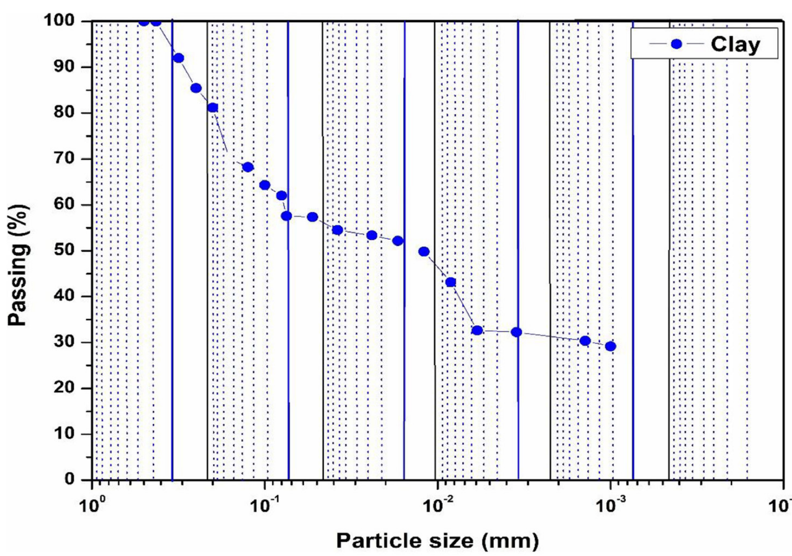

Figure 2. Particle size curve of clay studied.

According to the (Skempton, 1953) classification, based on activity, the predominant mineral in our clay is illite-kaolinite. The blue value, VB (methylene blue test) is used to deduce the total specific surface area (*SSA*) value using the (Lan, 1981) formula (Equation 2). This surface area reaches 189 m²/g. According to the classification of (Lautrin, 1989), and based on the total specific surface, our clay is likely to swell.

$$SSA = 21 \times VB \text{ (2) } (VB \text{ in the range } 0 - 2\ \mu m) \qquad (2)$$

2.1.2 Lime

The lime used in this study is that of Saida in south-west of Algeria. It is a slaked lime with a low concentration of oxide elements such as silicates SiO_2, aluminates Al_2O_3, magnesium oxide MgO (and a high concentration of basic elements such as free lime CaO, with an absolute density of 2.559 g/cm³ and a specific surface area of 11053 cm²/g. The percentages of lime used in our study vary from 2% to 8% with a step of 2%. Table 3 shows the chemical composition of lime.

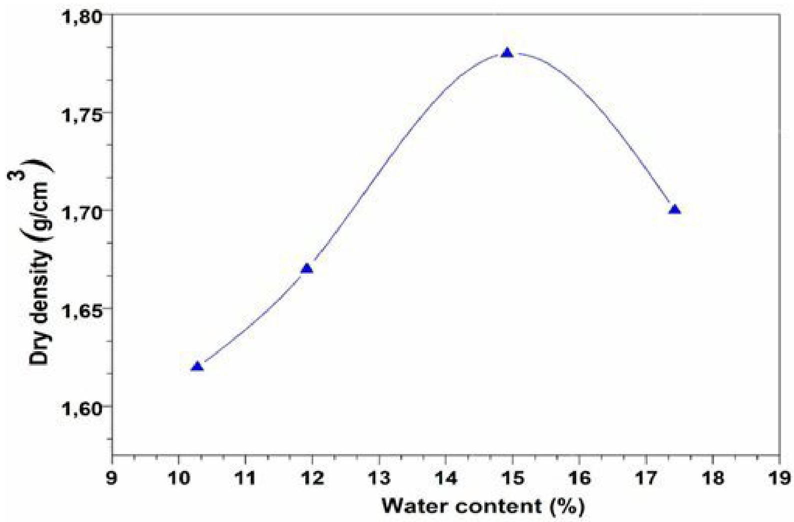

Figure 3. Proctor normal curve of clay.

Table 3. Chemical composition of lime.

Cao	Mgo	Fe_2O_3	AL_2O_3	SiO_2	SO_3	CO_2	$CaCO_3$
>67.4%	<0.4%	<2%	<1%	<2.2%	<1%	<5%	<10%

Table 4. Chemical composition of cement.

SiO_2	Al_2O_3	Fe_2O_2	CaO	MgO	SO_3	K_2O	Na_2O	Cl
19.70%	4.52%	3.49%	62.15%	1.79%	2.27%	0.49%	0.25%	0.02%

2.1.3 Cement

The cement used in our work is an artificial Portland cement from M'sila (Algeria) company (CPA-CEM I42.5). It is composed of 95% clinker and 5% gypsum, for the regularization of the setting with a density of 3.06 g/cm^3 and a specific surface area of 3918 cm^2/g. In our study, cement percentages were taken similar to those of lime. Table 4 presents the chemical composition of cement.

3. Indirect and direct measurements of swelling potential

3.1 Indirect measurements of swelling potential

Swelling clays have very specific physical characteristics that allow us to give a preliminary idea of their behavior with regard to swelling (indirect measurement of swelling potential). In addition, the measurement of swelling parameters is necessary (direct measurement). The indirect measurements are measures for predicting expansive soils from geotechnical identification tests before starting the treatment of this soil, in other words they are measures to predict against the disorders caused by this phenomenon before stabilization.

A considerable number of empirical approaches introduced by various authors, based on soil characteristics that are easily determined in the laboratory, are used for assessing swelling potential. Some approaches are based on a single parameter, and others on a combination of two or three parameters. The greater the combined parameters number, the better the assessment of swelling potential. Among these approaches one can cite: Dakshanamurthy & Raman (1973) on liquid limit (*LL* (%)), Costet et al. (1969) on plasticity index (*PI* (%)), *BRE* (BRE Building Research Establishment, 1980) (building research establishment) on *PI* (%) and (%2µm) Snethen et al (1977) with *LL* (%) and *PL* (%), Williams & Donaldson (1980) based on (%2µm) and *PI* (%) Holtz & Gibbs (1956) on (%1µm, *PI* (%) and shrinkage limit *SL* (%)), Holtz & Gibbs (1956) on *PI* (%), *SL* (%) and *LL* (%). Based on the values obtained for the studied soil, cited in Table 1, (*LL*=33%, *PL*=16%, *PI*=16.3%, *SL*=17.07%, %2µm =32.33% and (%1µm =31.69%), all classifications confirm that our clay has an average swelling rate. It now remains to confirm these classifications by direct measurements of the swelling parameters.

3.2 Direct measurement of swelling parameters

3.2.1 Free swelling measurement

The free swelling of a soil or rock element whose initial physical state is known, is the maximum deformation caused by the imbibition of this element subjected to a state of zero or near-zero stress (Serratrice & Soyez, 1996). The aim of this step is to determine the free swelling of clay on samples reconstituted by quasi-static compaction. Free swelling tests are carried out in a conventional oedometer. The sample is placed in a cylindrical cell between two porous stones. Then, following imbibition, it is allowed to inflate vertically under the pressure of the piston for several days until stabilization (Serratrice & Soyez, 1996). The final value allows to calculate the relative variation of the volume of the sample noted by *S*, which is often expressed as a percentage. It is determined according to the following formula (Equation 3):

$$S(\%) = \frac{H_f - H_0}{H_0}.100 \tag{3}$$

with H_0 the initial height, and H_f the final height after stabilization.

After 4 days, the free swelling of the Laghouat clay tends toward stabilization, and the *S* (%) value reaches 11.8%. This may result in geotechnical disorders (cracks) as those shown in Figure 4. Remeber that these pictures were recorded at site level (life base pumping station No. 5).

3.2.2 Measurement of swelling pressure

Several methods have been proposed for measuring swelling pressure using an odometer. The most widely used test is the constant volume swelling method (ASTM "American Society for Testing and Materials" D 4546-90, ASTM, 1990). This method is summarized as follows: The tendency of the sample to swell is neutralized by applying an increasing load as soon as the displacement of the comparator reaches 1/100 mm. The value of the load when the sample is stabilized is the swelling pressure (Chen, 1988). The free swelling and the swelling pressure are respectively denoted *S* (%) and *PS* (kPa).

4. Methods

Hydraulic binder mixtures were prepared by partially replacing water with 2–8% lime or cement, in 2% increments, expressed as a percentage of the dry weight of the soil. Prior to mixing, the clay was air-dried, crushed, and sieved through a 2 mm mesh. The required amount of lime or cement was first dry-mixed with the soil using a mechanical mixer for approximately 5 minutes to ensure uniform distribution. Distilled water corresponding to the target water content was then gradually added, and mixing was continued for an additional 10 minutes until a homogeneous mixture was obtained. For lime–water mixtures, the prepared samples were cured for 24 h at room temperature (20 ± 2 °C) in sealed containers to prevent moisture loss. For cement–water mixtures, measurements were taken immediately after sample preparation, in accordance with previous studies (Derriche & Kebaili, 1998; Cabane, 2004; Al-Rawas et al., 2005). Samples were statically compacted to a dry density of γd = 17 kN/m^3 and a water content of *W* = 15%, using a hydraulic press at a loading rate of 1 mm/min. The cylindrical specimens had dimensions of 20 mm in height and 50 mm in diameter. Each test was performed on at least three identical specimens, and the reported results represent average values. After preparation, all samples were stored in airtight containers to maintain constant moisture conditions until testing. Swelling behavior was assessed using both indirect and direct methods. Indirect evaluation was conducted using empirical classifications based on Atterberg limits and plasticity indices.

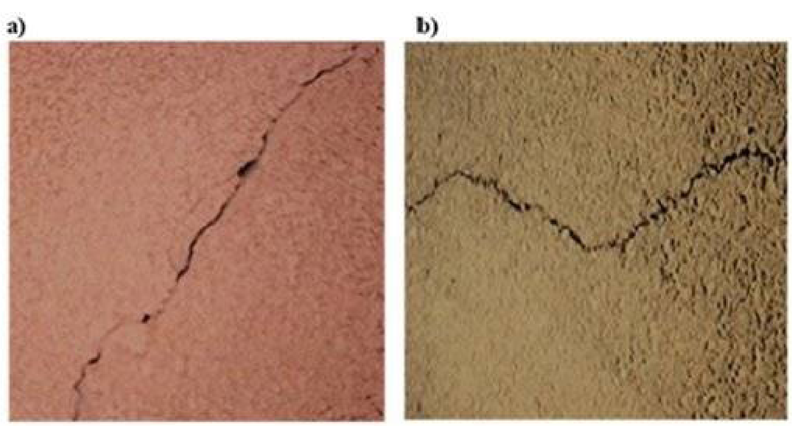

Figure 4. Disorders caused by the shrinkage-swelling phenomenon at life base site of pumping station No. 5 (a) Inclined crack on the wall; (b) Destruction of the roadway.

Direct measurements were performed using oedometer tests to determine free swelling and swelling pressure. This combined approach enables a systematic evaluation of the effects of low-percentage lime and cement binders on the swelling behavior and shear strength of the local illite–kaolinite clay from Laghouat.

5. Results and discussions

5.1 Effects of different treatment types on consistency limits

Soil stabilization with lime or cement is used to reduce swelling by modifying the alkalinity and structure of the soil. Lime, in particular, neutralizes soil acidity, reduces its plasticity, and improves its water retention capacity. Cement, on the other hand, creates a hard matrix that strengthens the soil and makes it less sensitive to humidity variations. Lime and cement are widely used in all construction applications. In our work, low percentages of lime and cement were chosen for the stabilization of this expansive soil.

Table 5 presents the consistency values obtained for the different percentages. Figures 5 to 7 show the variations of liquid limit (*LL*), plasticity limit (*PL*), and plasticity index (*PI*) for the different types of clay stabilization.

From these findings, it can be said that the effect of lime and cement is similar on the consistency limits, it is clear that they lead to decreases in the consistency of clay. Lime reduces the liquid limit and an increase in the plasticity limit and consequently the reduction in the plasticity index, while cement has a similar effect as lime for the liquid limit (Handy, 1961; Bell, 1994; Smaida et al., 2021) and the plasticity index but a decrease in the plasticity limit. These effects on consistency are indirect indices on the swelling parameters as will be shown in the indirect measurements of the swelling parameters (free swelling and swelling pressure). There is a very appreciable reduction in the liquid limits for the percentage of 8% lime and cement which is (65% and 50%) respectively, likewise, a significant reduction in the plasticity index (91%) for 8% lime (Smaida et al., 2021, Bekhiti et al., 2019).

Table 5. Results of consistency limits for lime and cement mixtures.

		Liquid Limit (LL) (%)	Plastic Limit (PL) (%)	Plasticity Index (PI) (%)
	Clay	33	16.7	16.3
Lime (%)	2	30.46	16.8	13.66
	4	22.40	18.2	4.20
	6	21.75	18.1	3.65
	8	20.12	18.3	1.82
Cement (%)	2	24.14	13.8	10.34
	4	21.20	12.71	8.49
	6	17.51	10.22	7.29
	8	16.48	10.41	6.07

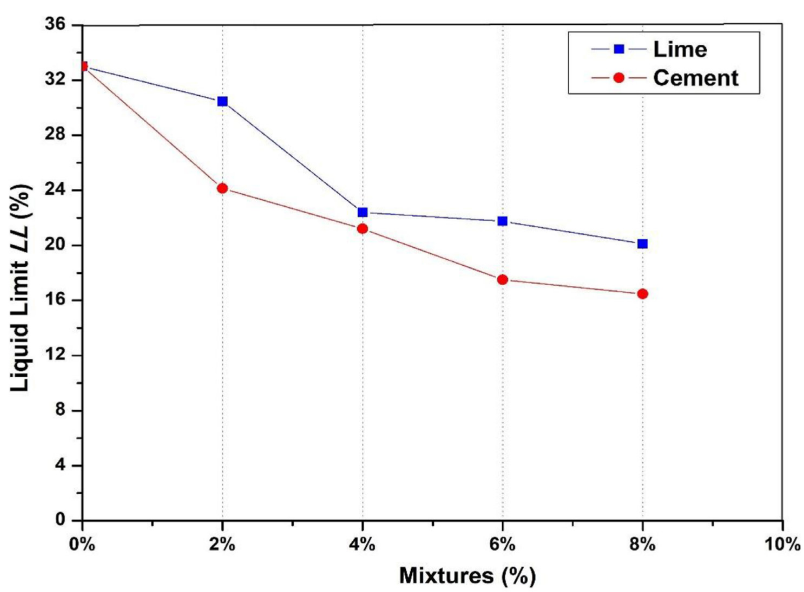

Figure 5. Variation of *LL* according to the percentages of lime and cement.

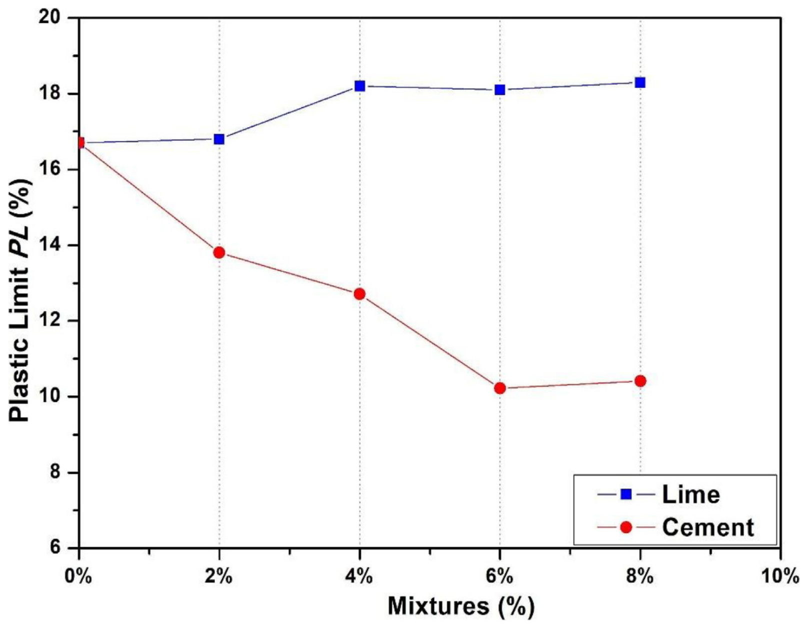

Figure 6. Variation of *PL* according to the percentages of lime and cement.

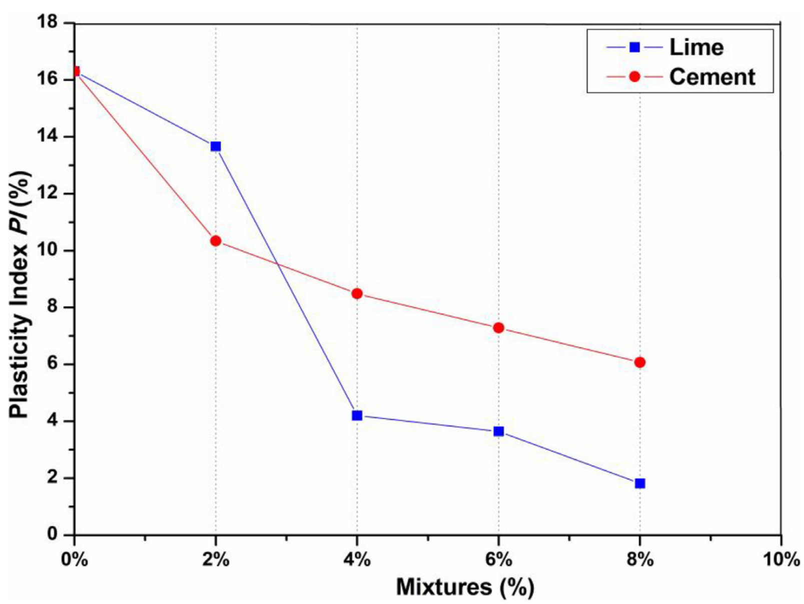

Figure 7. Variation of *PI* according to the percentages of lime and cement.

5.2 Effects on swelling potential and swelling pressure

Figure 8 illustrates the variation of swelling potential for the adopted stabilization techniques (lime and cement) as a function of time. Figure 9 shows the variation of free swelling and swelling pressure as a function of the percentage of lime and cement, respectively. Equations 4 and 5 give the way to calculate the free in and the inflation pressure. Table 6 summarizes our obtained results on the parameters of swelling.

$$\frac{\Delta S}{S}(\%) = \frac{S_0 - S_t}{S_0} \times 100 \tag{4}$$

$$\frac{\Delta PS}{PS}(\%) = \frac{PS_0 - PS_t}{PS_0} \times 100 \tag{5}$$

S_0, PS_0 are respectively the free swelling and swelling pressure of untreated clay.

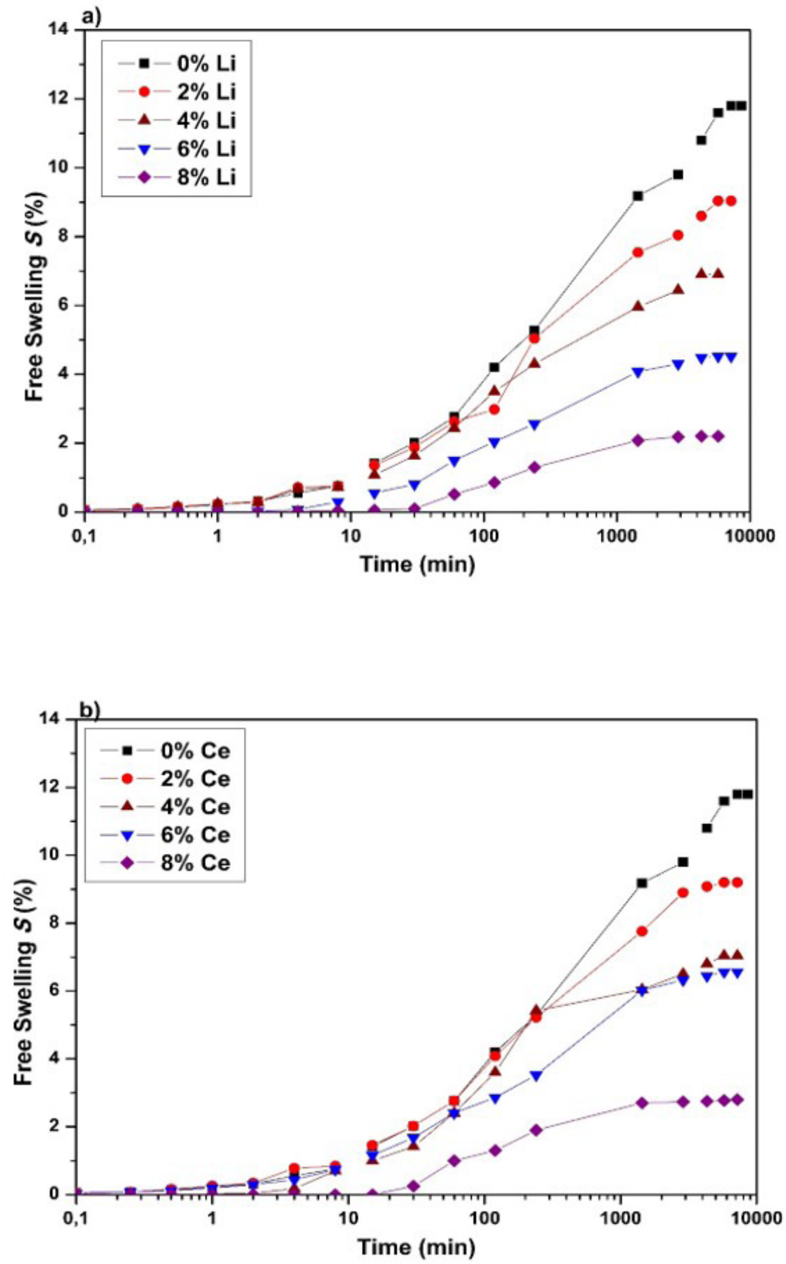

Figure 8. Variation of free swelling as a function of time for (a) Lime; (b) Cement.

Table 6. Parameters of swelling for different percentages of lime and cement.

Clay		Free swelling S (%)	Swelling reduction ΔS /S (%)	Pressure swelling PS (kPa)	Reduction of swelling Pressure, ΔPS/Ps (%)
		11.8	/	**155.4**	/
Lime (%)	2	9.04	23.39	96.8	37.71
	4	6.90	41.52	40.8	73.74
	6	4.52	61.69	28.0	81.98
	8	2.20	81.35	15.3	90.15
Cement (%)	2	9.20	22.03	107	31.14
	4	7.04	40.33	38.2	75.42
	6	6.56	44.41	28.0	81.98
	8	2.80	76.27	20.4	86.87

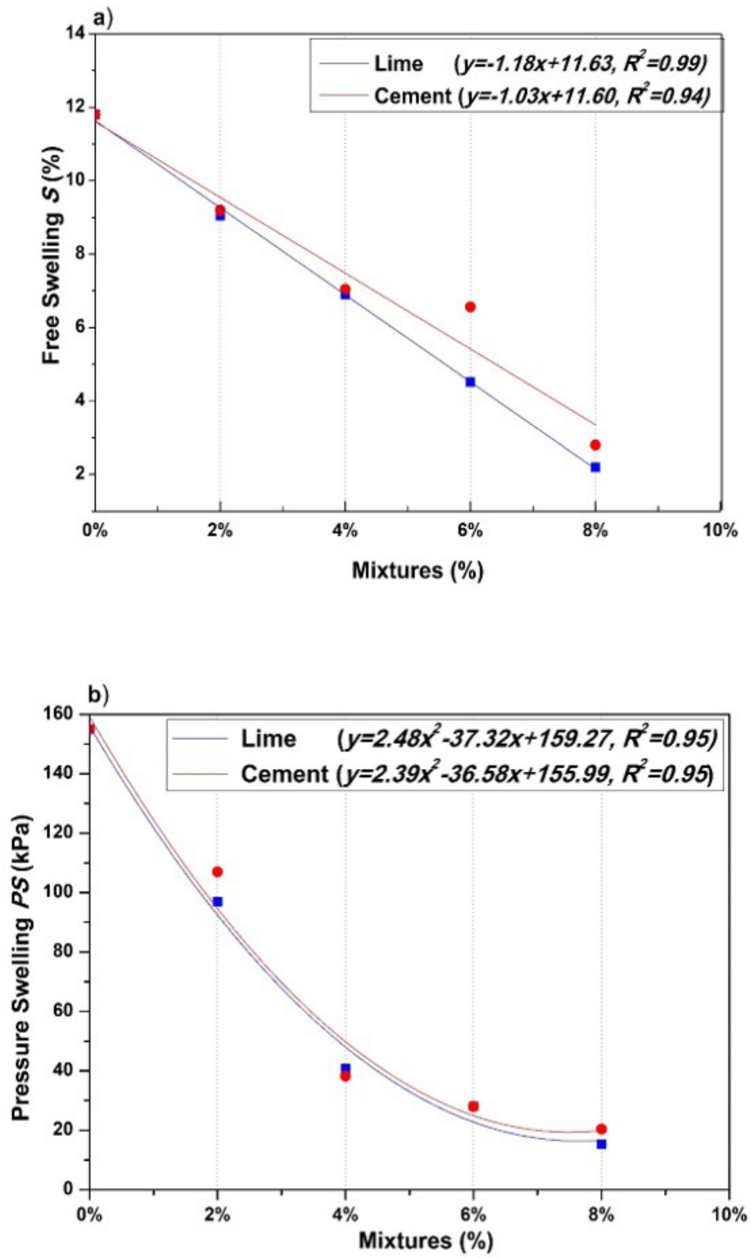

Figure 9. Variation of (a) Free swelling according to the percentage of lime and cement; (b) Swelling pressure according to the percentage of lime and cement.

S_t , PS_t are respectively the free swelling and swelling pressure of treated clay.

Note that Li and Ce denote lime and cement, respectively.

Stabilization by adding lime is the most widespread soil treatment technique. The use of this technique allows clay soils to be given a good consistency fairly quickly (Djedid et al., 2001). Lime treatment has shown certain changes that occur on the characteristics of the soil such as the decrease in water content (Djedid et al., 2001). Additively to the exchange of Na^+ and K^+ cations by Ca^{2+} and the flocculation of clay particles caused by electrical forces (Petry & Little, 2002; Gueddouda et al., 2011; Smaida et al., 2021), the consistency increases which has a direct relationship with the swelling phenomenon, this consistency leads to a manageable product that is easy to compact. The optimal quantity to have these changes is called the lime fixation point. Beyond this point, various cement formation processes occur, increasing the strength of the soil. Cement is among the most frequently used binders in the treatment of surface soils (Johnson, 1960). The action of stabilization by cement is complex and depends on the nature of the soil, the cement content, the water content and the temperature conditions (Nalbantoglu & Gucbilmez, 2001).

In addition, the presence of lime in cements causes exchange reactions. The studies of (Sherwood, 1995; Smaida et al., 2021) have shown that stabilizing clay soils with lime transforms them into firm soils and improves their strength, permeability and stabilizes their volumes after swelling and shrinkage. According to Figure 8 and Table 6, the effect of lime and cement are similar as these two binders reduce the swelling rate in accordance with (Gueddouda et al., 2011; Smaida et al., 2021; Bekhiti et al., 2019). According to the results obtained in Figure 9 and Table 6 at a low percentage 2% of lime and cement the reduction of swelling is ($\Delta S/S$) %=23.39%) and (($\Delta S/S$) %=22.03%)) with a reduction of swelling pressure (($\Delta P_S/P_S$) =37.71%) and (($\Delta P_S/P_S$) =31.14%). The same remark can be done for percentages 4%, 6%. For the percentage of 8%, a significant reduction of the swelling rate (($\Delta S/S$) % ≅81%) is noted for 8% of lime and the same for 8% cement (($\Delta S/S$) % ≅76%) thus, for the swelling pressure; a reduction of (($\Delta P_S/P_S$) % ≅90%) for 8% lime and of (($\Delta P_S/P_S$) % 86%) for 8% cement (Gueddouda et al., 2011; Bekhiti et al., 2019; Smaida et al., 2021). Regression analyses were performed to quantify these trends. Free swelling ($\Delta S/S$ %) decreases linearly with binder content, with $R^2 = 0.99$ for lime and $R^2 = 0.94$ for cement, indicating a nearly proportional reduction. Swelling pressure ($\Delta PS/PS$ %) follows a second-degree polynomial relationship, with $R^2 = 0.95$ for both lime and cement, showing a more pronounced reduction at higher binder percentages. These regression results provide a quantitative framework for predicting the effects of lime and cement on clay stabilization.

5.3 Effects on shear strength

The objective of this experimental section is, first, to determine the shear strength parameters of the treated clay, namely the angle of internal friction and cohesion, and to demonstrate the effect of adding lime and cement on these parameters. For this, the direct shear test, unconsolidated and undrained test case denoted UU (NF P94-071-1, AFNOR, 1994), were used. The test condition used in this study is the unsaturated state (constant water content). The samples mixed with the same solutions prepared during swelling parameter measurements and compacted in the same manner (static compaction). These samples were cut using a cutting kit with the same dimensions as the shear cell (square, 6 cm side and 2 cm height).

To ensure that the contact surface is flat, the sample is leveled and smoothed on both sides, top and bottom, with voids filled. After the sample preparation phase, the sample is placed in the shear box. The samples will be directly sheared at the initial water content. The normal stresses used to conduct these tests are: σ_1=100 kPa; σ_2=200 kPa; σ_3=300 kPa. The shear rate used is 1mm/min. The percentages of lime and cement selected are 2% and 6%. Figure 10 shows the induced curves for the different lime and cement mixtures respectively. Table 7 summarizes the results of these direct shear tests.

Note that: τ_{1pic}: Maximum shear stress at σ_1=100 kPa.

τ_{2pic}: Maximum shear stress at σ_2=200 kPa.

τ_{3pic}: Maximum shear stress at σ_3=300 kPa.

Many previous studies have shown that stabilizing clay soils with lime and cement transforms them into firm soils and improves their strength (Smaida et al., 2021), their permeability and stabilizes their volumes after swelling and shrinkage (Gueddouda et al., 2011; Smaida et al., 2021). The mechanism responsible for these changes (pozzolanic reaction) occurs between the silica and/or alumina in the soil and lime to form certain types of cementing or solidifying agents. The result of these reactions plays the most important role in increasing the strength of the soil-lime mixture, the properties acquired by the soil can last for years. This phenomenon is the main cause that ensures the good stabilization of the soil/lime or cement mixture. According to the obtained results shown in Table 7 and Figure 10, it can be seen that the maximum shear strength increases with the different percentages added, whether lime or cement. The percentage of 6% of lime and cement leads to cohesion of 185 kPa and 313 kPa respectively. These values are higher than that obtained for untreated clay (111 kPa) and higher than those obtained in the percentage of 2% (147 kPa and 121 kPa), respectively.

Table 7. Results of direct shear tests.

	Clay	2% Lime	6% Lime	2% Cement	6% Cement
Cohesion (kPa)	111	147	185	121	313
Friction angle (°)	40	43	40	50	30
Max shear stress (kPa) (τ_{1pic}) at σ_1=100kPa	151	159	184	113	328
Max shear stress (kPa) (τ_{2pic}) at σ_2=200kPa	247	228	247	276	385
Max shear stress (kPa) (τ_{3pic}) at σ_3=300kPa	252	410	430	437	442

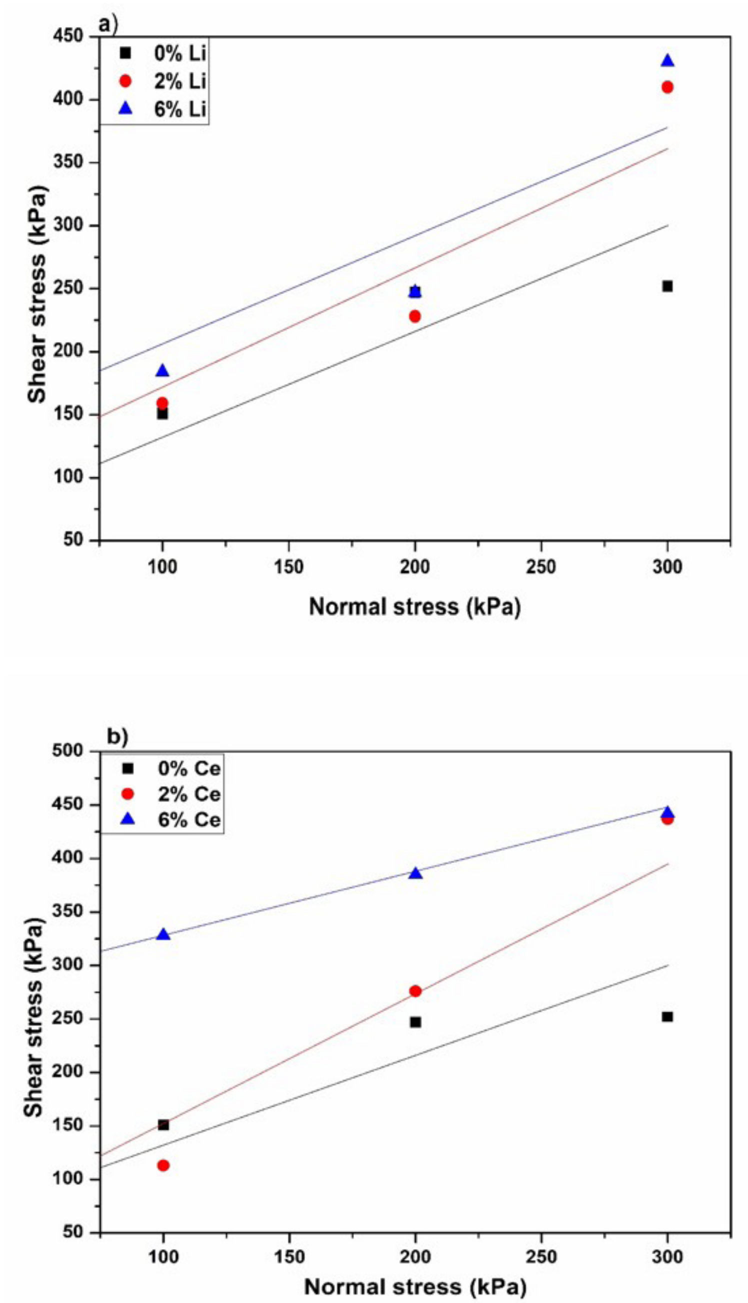

Figure 10. Intrinsic curves for mixtures (a) lime; (b) cement.

6. Conclusion

The aim of this study is to inspect the effect of hydraulic binders on the swelling parameters and shear strength of Laghouat clay (Laghouat clay, SP5 base de vie). The results show that the use of lime and cement, at low percentages, to stabilize swelling soils can reduce swelling potential and swelling pressure. Lime, in particular, can significantly reduce soil moisture by reaction with water, while cement acts by cementing clayey blocks and reducing the plasticity index. These results led to the following conclusions:

- The estimated swelling parameters obtained by the two indirect and direct methods are very close. Hence, a primary identification based on simple test results can be of considerable interest, since it will enable us to better predict the behavior of soils with respect to the swelling phenomenon.
- Lime causes a reduction in the liquid limit and an increase in the plastic limit, and consequently a reduction in the plasticity index, with a marked reduction in 8% lime and around 20% in the liquid limit (*LL* (%)) and 91% in the plasticity index (*PI* (%)).

- Cement has a similar effect to lime for liquid limit and plasticity index, but with a reduction in plasticity limit, noting a reduction of around 16% in liquid limit (*LL* (%) and 62% in plasticity index (*PI* (%)).
- A progressive reduction was recorded for swelling parameters with the addition of lime and cement at 8% lime, the reduction in swelling potential is of the order of 81% and 90% for swelling pressure, at 8% cement, the reduction is 76% for swelling potential and 87% for swelling pressure.
- Shear strength increases proportionally at the lower percentages (2% and 6%) for lime and cement, reflecting the increased cohesion between particles, whereby cohesion increased from 111 kPa of untreated clay to 185 kPa in the case of 6% lime and to 313 kPa for the case of 6% cement.

Accordingly, the use of lime and cement is an effective method for stabilizing soils against swelling and increasing their shear resistance with no environmental concerns because of the low percentages of the used materials.

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Declaration of interest

The authors have no conflicts of interest to declare. All co-authors have observed and affirmed the contents of the paper and there is no financial interest to report.

Authors' contributions

Smaida Ali: conceptualization. Smaida Ali, Dif Fodil, Belkacem Mekerta: methodology.Smaida Ali, Dif Fodil, Gueddouda Mohamed. Kamel: investigation. Smaida Ali, Hayet Cherfa, Smail Haddadi: discussion of results. Smaida Ali: writing - original draft, writing - reviewing and editing. Mekerta Belkacem, Cherfa Hayet, Haddadi Smail: resources. Smaida Ali, Gueddouda Mohamed. Kamel: supervision. Smaida Ali, Gueddouda Mohamed. Kamel, Hayet Cherfa, Latreche Khalil: approval of the final text.

Data availability

The datasets generated and analyzed in the course of the current study are available from the corresponding author upon request.

Declaration of use of generative artificial intelligence

This work was not prepared with the assistance of Generative Artificial Intelligence (GenAI).

List of symbols and abbreviations

n	Correction factor (non-active or non-plastic fraction)
Ac	Clay activity
ASTM	American Society for Testing and Materials
Ce	Cement
CPA	Artificial Portland cement (M'sila, Algeria)
C_2	Percentage of particles smaller than 2 µm (clay fraction)
H_0	Initial height
H_f	Final height after stabilization
LEEGO	Laboratory of Environment, Water, Geomechanics and Structures, USTHB, Algeria
LGCDD	Civil Engineering and Sustainable Development Laboratory, University of Djelfa, Algeria
Li	Lime
LL	Liquid limit
NF	French standards
PL	Plastic limit
PI	Plasticity index
PS	Pressure swelling
PS_0	Pressure of untreated clay
PS_t	Pressure swelling of treated clay
R^2	Coefficient of determination
SL	Shrinkage limit
SSA	Specific surface area
S	Free swelling
S_0	Free swelling of untreated clay
S_t	Free swelling of treated clay
USTHB	University of Science and Technology Houari Boumediene
UU	Unconsolidated Undrained test (NF P94-071-1, AFNOR, 1994)
VB	Blue value
W	Water content
W_{OPN}	Optimal water content
XRD	X-ray diffraction
ΔPS	Reduction of swelling pressure
ΔS	Reduction of free swelling
γ_d	Dry density
γ_{dmax}	Maximum dry density
σ_1, σ_2, σ_3	Normal stresses
$\tau_{1\,pic}$, $\tau_{2\,pic}$, $\tau_{3\,pic}$	Maximum shear stresses

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