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Chemical Stabilization of Expansive Clays from Algeria

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CHEMICAL STABILIZATION OF EXPANSIVE CLAYS FROM ALGERIA

Strictly as per the compliance and regulations of:

Chemical Stabilization of Expansive Clays from Algeria

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Abstract - The occurrence of expansive clays causes serious stability problems in regions with arid climate. In these areas, the clay is so dry that a supply of a tiny quantity of water may release a fantastic energy capable of producing important damage in structure. This paper presents the chemical stabilization of three soils. In the first part, the potential swelling is estimated using indirect methods based on the geotechnical characteristics, thereafter, direct measurement of swelling parameters (magnitude and pressure of swelling) is carried out. The second part, deals with the study of the treatment of clays using several methods of stabilization (addition of NaCl salt, lime, cement, and association lime+ cement, and association lime + salt). The obtained rresults are very encouraging and show that for certain combinations the reduction rate in swelling potential is very important (about 90%).

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I. Introduction

Expansive soils are those which show volumetric changes in response to changes in their moisture content. Such soils swell when the moisture content is increased and shrink when the moisture content is decreased. Consequently, expansive soils cause distress and damage to structures founded on them. Algeria has witnessed tremendous development in its infrastructure over the last three decades. The problems of expansive soils seem to be overlooked during the design and construction of some of the projects especially in arid and semi-arid region (Lamara *et al.* 2005). As a result, some of these structures in Algeria were subjected to distress and damage and in worst cases some houses and roads were demolished.

The problems associated with expansive soils in Algeria are predominantly related to the presence of smectite clay minerals in tertiary rocks and quaternary soils. Expansive materials that exhibit swelling problems include bentonite mudstones, marls and silty mudstones, argillaceous limestones and altered conglomerates. The climate in Algeria is arid, with high evaporation rates, so that there is always a moisture deficiency in soils and rocks. Supply of water from any source is liable to cause ground heave in any soils or rocks possessing swelling potential. Damage caused by swelling soils for buildings and structures are considerable light (Tas 1992, Derriche et Kebaili 1998, Hachichi et Fleureau 1999, Djedid *et al.* 2002, Lamara *et al.* 2006).

However, in order to limit the disturbances in buildings, various solutions based on stabilization techniques have been developed with more or less satisfactory results. Stabilized soil is change some of these properties to improve its technical performance. Recently, Extensive studies have been carried out on the stabilization of expansive soils using various additives such different types of sand (quarry sand, dune sand and beach sand) and the dune sand combination + salt (NaCl) appeared to give encouraging results(lamara *et al.* 2006, Gueddouda *et al.* 2006-2007). These solutions have been developed to minimize the pressures on soil saturation.

The work presented in this paper is a contribution to the application of chemical stabilization techniques, by adding salt (NaCl) for different concentrations lime, cement, association lime + cement, and association of lime and salt for Three different clays, two clays belonging to different arid regions of southern Algeria and a very expansive clay known as Bentonite Maghnia (in the region of Tlemcen), where several cases were reported disorders characterized by cracks in the superstructure and the foundation level.

Initially, the chemical, physical and geotechnical properties of the untreated soils were determined. These tests were complemented by direct measurements of the swelling parameters (free swell and swell pressure). Secondly, the study examined the effects of different types of stabilization on the physical properties and the swelling parameters.

II. Materials Used for Study

a) Localization of the soils

The first soil is extracted from an area located 20 km northwest of the city of Laghouat (Basis of Life, Pumping Station No. 5); this region is considered semi-arid to arid, located 400 km south of the capital Algiers (Fig. 1). From the geological point of view, this zone presents several layers of which the first is covered with a vegetable layer a thickness of approximately 30 cm

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followed by a layer of silt and sandy-gritty, finally a layer of greenish and reddish marls with presence of gypsum crystals at a depth of over 1m. Our sample is extracted at a depth of 3.5 m (3rd layer). This soil is named ELG.

The second soil extracted from the In-Amenas region, this region is considered arid to very arid region located 1600 km south of the capital Algiers (Fig.1). Several studies have been conducted on this soil. The synthesis of these studies shows that the clays in this region occur along a stratigraphic fairly regular succession according to different layers. A sandy cover of about ten centimetres, an upper layer consists of silty clay material reddish color and a thickness of 1.5 m, a compact clay layer of darker color than the upper layer, and finally a layer greenish are relatively thin soil (Tas 1992, Kaoua and Derriche 1994, Derriche and Kebaili, 1998). The soil studied was extracted in the third layer. This soil will be named (EAM).

The term 'Bentonite' is now well established, and used to describe a clay material whose major mineralogical components belong to Smectite groups. As a result, bentonite is a very expansive soil. The most important bentonite mines in Algeria are situated in the western regions (Fig. 1). The bentonite used in this study is extracted from Maghnia mine (Hammam Boughrara, 600 km west of the capital Algiers).

b) Characterization of the soils

The physical characteristics of the untreated soil are shown in Table 1. All geotechnical tests were performed in accordance with British Standard 1377. Based on Casagrande plasticity chart, this soil ELG and EAM was classified as of high plasticity clay. These soils showed a high plasticity index 35% and 40% respectly and an activity of 1 and 0.75 respectly. The bentonite of Maghnia it is very fine clay; more than 60% of particles have a diameter less than 2 µm. The value of the liquidity limit and Plasticity Index LL= 141%, PI = 93% respectly; indicate that the bentonite of Maghnia is highly plastic clay, this is also confirmed by a large specific surface (Ss = 462 m^2/g). According to the Skempton classification (Skempton 1953), based on the activity (Eq. (1)), the bentonite of Maghnia presents a high percentage of calcite Montmorillonite (Ca^{+2}).

Generally, the higher the plasticity index and activity of a soil, the higher the swelling potential. According to the Van der Merwe (1975) classification system, the soil was classified as having high swelling potential.

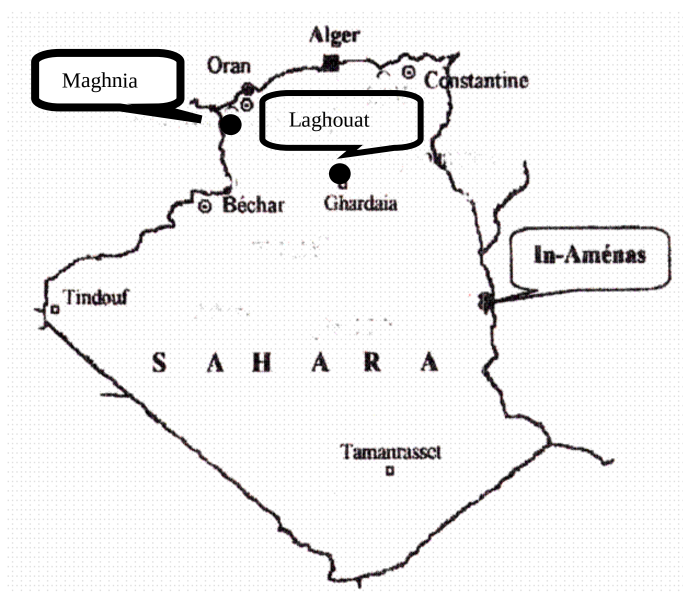

Figure 1: Localization of the soils

Table1 : Physical characteristic of the soils

	%<2µ	LL (%)	PI (%)	LS (%)	A	γ_d (kN/m^3)	w_{opt} %	Sst (m^2/g)
ELG	36	69	35	12	1	17.8	15	189
EAM	55	62	40	13	0.7	18	13	437
B	60	141	93	9	1.55	12	34	462

$$\text{Activity}: \ A = \frac{IP}{\%<2\mu m} \qquad (1)$$

The mineralogical and chemical of the untreated soil are shown in Table 2. From chemical analysis, the main mineralogical constituents of the three soils are silica and alumina. For soil ELG, the presence of high percentage of calcium carbonate (CaO) indicates to us that this ground belongs to the group of clays limestones. The potassium K_2O content in soil EAM confirms the presence of Illite. Moreover, we note that the three soils present percentages in SiO_2 lower than 80%, boundary value between the swelling soil and not swelling soil (Hachichi and Fleureau 1999) which predicts that these soils have a natural tendency to swell. X-ray diffraction is one of the most widely used methods for clay minerals identification and studying their crystal structure within the soils. Diffraction test carried out on bentonite, showed that the predominant clay minerals are smectic types; beside it reveals also the presence of Illite, quartz, and traces of kaolinite.

Table 2 : Chemical analysis of soil

%	SiO_2	Al_2O_3	Na_2O	CaO	K_2O	MgO	Fe_2O_3	M.O
ELG	58.94	10.03	0.35	17.70	2.01	0.7	1.02	9 .56
EAM	56.3	15.12	2.36	2.56	2.4	1.43	7.0	12.83
Bentonite	65.2	17.25	3	5	1.7	3.1	2.1	2.65

III. Study of Swelling Clays

a) *Estimation of swelling potential*

A considerable number of empirical approaches proposed by different authors are used to evaluate the swelling potential. These approaches are based on physical characteristics of soil (LL, PL, PI, C_2); Skempton 1953, Seed *et al.* 1962, Ranganathan and Satyanaryana 1965, Vijayverjya and Ghazzaly 1973, Williams and Donaldson 1980, Mouroux *et al.* 1988, Holtz and Gibbs 1996. However, models for predicting swelling are rude. Direct measurements of swelling parameters are needed to confirmed and quantify the swelling of clay. Generally, all classifications show that soils ELG and EAM tended a high rate of swelling, while for Bentonite; it has a very high rate of swelling, which in agreement with the mineral montmorillonite is predominant.

b) *Direct Measurement of swelling parameters*

Many researchers have used the term swelling potential. However, a clear definition of the term has not been established. Generally, swelling potential has been used to describe the ability of a soil to swell, in terms of volume change or the pressure required to prevent swelling. Therefore, it has two components: the swell percent which is defined as the percentage increase in height in relation to the original height, and the swell pressure which is designated as the pressure required to prevent swelling.

i. *Measurement of swelling potential*

Swelling tests are carried out using a standard one-dimensional oedometer. Dimensions of samples are 50 mm in diameter and 20 mm in height. The test is realized according to the free swelling method (Serratrice and Soyez 1996)). The soils samples are prepared by a static compaction (velocity of 1 mm/min) for water contents and dry densities corresponding to the Optimum Proctor Conditions. The sample is placed in a cylindrical cell between two porous stones. Then, by imbibition, it is authorized to swell vertically under the pressure of the piston during several days until stabilization. The total free swelling (G %) is computed using the following relationship (Eq. 2) :

$$G\,(\%) = \frac{(Hf - H0)}{H0} \times 100 \qquad (2)$$

$\Delta H = H_f - H_0$

H_0: initial height (before swelling)

H_f: final height (after swelling)

ii. *Measurement of swell pressure*

Two methods to measure the swelling pressure to the œdometer were used:

- Method of free swelling: After the free phase of swelling under weak load (weight of the piston), the quasi saturated sample follows a way of loading until its volume returns to its initial value. The corresponding constraint is the swelling pressure (Chen 1988).
- Method of constant volume: this method is carried out according to standard ASTM D 4546-90 (American Society for Testing and Materials). It consists in neutralizing the swelling of the sample by the application of an increasing load as soon as the displacement of the comparator reaches 1/100 mm. The addition of loads was continued until deformation ceased. At this stage, the value of the load when the sample is stabilized represents the swelling pressure (Chen 1988, Serratrice and Soyez 1996).

c) *Results*

Figure 2 shows the evolution of free swelling (G %) according to time for the three soils. It is noted that during the imbibition, the swelling soil in a similar way. The evolution of free swelling presents two phases: primary swelling where the evolution is fast and a secondary swelling where the evolution is less slow. In general, after 7 days, the swell percent are of 20% for the soil of Laghouat (ELG) and from approximately 30% for the soil of In Amenas (EAM). The bentonite present a very important swell percent, it about 70% (Gueddouda *et al.* 2010). The obtained results show the swell character of the soils and confirm the observations obtained using the indirect methods.

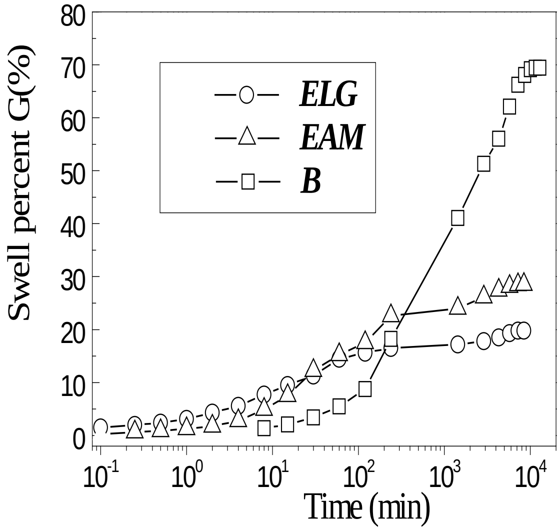

Figure 2 : Swelling evolutions of soils versus time

The results of swell pressures summarized in Table 3. It is noted that the three soils develop very significant swell pressures. The bentonite of Maghnia swell pressure develops a very important; it is of the order of 900 kPa. For soils ELG and EAM, the swell pressures are about 400 and 480 kPa respectively.

Moreover, we note that the swelling pressure determined by the method of free swelling is higher than that obtained by the method of constant volume. This is consistent with the results given by Sridharan *et al.* 1986, Philipponnat and Huber 1997. This difference is attributed to the friction that develops during the recompression phase of the sample after free swelling.

Table 3 : Results of swelling parameters

	G%	Ps_1 (kPa)	Ps_2 (kPa)	Ps (kPa)
ELG	19.8	412.5	400	406
EAM	28.5	585	370	477
B	70	960	840	900

G% : free swell
Ps_1 : swell pressure (method of free swelling)
Ps_2 : swell pressure (method of constant volume)
Ps : Medium swell pressure

IV. Chemical Stabilization of Soils

The products used for the stabilization of the three soils are: salt, Lime and cement.The salt used is NaCl. Salt solutions (distilled water + NaCl) with the following concentrations: 0.1 M, 0.5 M and 1.5 M (M is the molality of the salt solution (M = mol / liter)).The lime used is that of the region of Saida and is a hydrated lime presenting a low concentration of elements such as silicates oxides SiO_2 (< 2%), Al_2O_3 and aluminates (< 1%) and a high concentration of basic elements as a free lime CaO (< 70%). The concentrations used are: 2%, 4% and 6%.The cement used is Portland cement composed (CPJ-CEM II / A) 42.5. The cement is fabricated of M'sila and available on the market. The concentrations used are: 2%, 4% and 6%.The preparation is made by cementing a substitution capacity of water by the percentages of lime or cement. For lime + water, the curing period is 24 hours, by cons for cement + water is immediate. The samples were prepared by static compaction at the OPN. The swelling potential is determined by the same methods used for soil untreated with imbibition saline and hydraulic binders.

a) *Stabilization of clays by salts, lime and cement*

The liquid limit and plasticity index of the untreated and treated samples are shown in Table 4. Hydraulic binders (cement or lime) conduct to lower liquid limits and plasticity index. Reductions in plasticity indices are important and can reach 60% for soils EAM and ELG for a percentage of 6% lime. The effects of hydraulic binders on bentonite are lower compared with soils ELG and EAM. The limits of liquidity reach a reduction of about 25% for a percentage of 6% lime. Generally, the effects of lime and cement are similar. This behavior is attributed to the cations exchange process between the cations of the soil and those of the stabilizers. The effect of salt (NaCl) leads to greater reductions in the limits of consistencies that hydraulic binder. The reductions reach about 75% for a concentration of 1.5 M.

Swell percent and swell pressure tests were carried out on untreated samples to measure these two parameters in order to examine the effect of the various additives on the reduction of the swelling potential of the soil Figure 3 shows the evolution of free swelling (G%) versus time for three soils with different types of stabilization. The swelling pressures of untreated and treated soils are summarized in Table 4. The swelling pressure shown is the medium of the swelling pressures obtained by two methods.

- Action of salt (NaCl) : Examination of the curves of evolution of free swelling as a function of time indicates that the reduction rate of free swelling by saline is proportional to the concentration of salt. For soils ELG and EAM and a low concentration of salt (0.1 M), reducing the swelling rate is only 20% and 18% for the swelling pressure. For a high concentration (1.5 M), reducing the swelling rate is around 60% and 80% for the swelling pressure. Moreover, we note that for a low concentration of 0.1 M, the reduction of swelling bentonite is about 40% and about 70% to swelling pressure, while for concentration of 1.5 M, reductions in swelling parameters are more important, it attains a reduction of more than 90% for the swelling pressure. It can be concluded that salt (NaCl) is more effective in reducing the swelling pressure as the rate of swell. These results are in good agreement with results obtained by Nalbantoglu 2001, Abu Baker *et al.* 2004, Bekkouche *et al.* 2007.
- Action of lime and cement : Increased percentage

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of lime and cement can reduce the swelling rate. For 6% lime, reducing the swelling rate can reach 70%. Similarly for cement or reduction is greater than 60%. The effect of lime appears to be important that the effect of cement. The same findings are obtained for the swelling pressure or the reduction exceeds 80%. For the same percentage of 6% lime, the swelling pressure of bentonite from 900 kPa to 135 kPa. For the EAM ground, it decreases from 477 kPa to 81 kPa for soil ELG; it goes from 406 kPa to 40 kPa. In general, the actions of lime and cement have similar effects on soil ELG and EAM, but the action of lime seems more important than that of cement to reduce the swelling pressure of bentonite. Lime affects the electric charges located around the clay particles and modifies the electric fields between the particles. When lime is added to clay soils in the presence of water, a number of reactions occur leading to the improvement of soil properties. These reactions include cations exchange, flocculation, carbonation and pozzolanic reaction. The cations exchange takes place between the cations associated with the surfaces of the clay particles and calcium cations of the lime. The effect of cations exchange and attraction causes clay particles to become close to each other, forming flock; this process is called flocculation. Flocculation is primarily responsible for the modification of the engineering properties of clay soils when treated with lime (Bell 1996, Al-Rawas 2002, Djedid *et al.* 2005). Cement stabilization is similar to that of lime and produces similar results. Cement stabilization develops from the cementations links between the calcium silicate and aluminate hydration products and the soil particles. When adding cement, cement powder moistened her in contact with moist soil and form a paste that coats the lumps. Cement is a cementing agent, it binds the particles together causing the stiffening of the soil and therefore it leads to reduced swelling parameters (Sherwood 1995, Nalbantoglu *et al.* 2001).

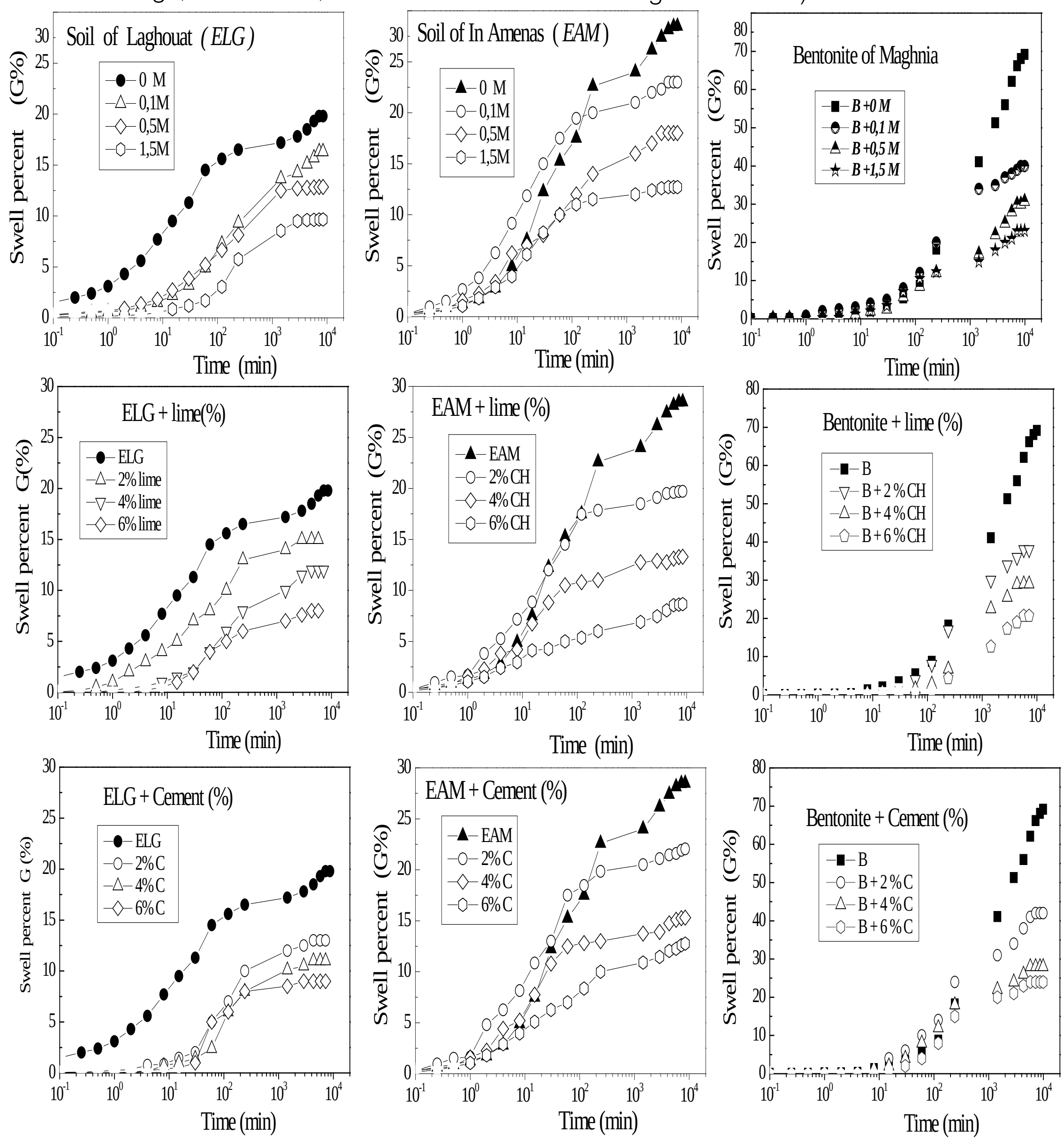

Figure 3 : Evolution of free swelling (G %) versus time for three soils with different types of stabilization

Table 4 : Geotechnical results of the treated samples

		LL	PI	G (%)	ΔG /G (%)	Ps (kPa)	ΔPs/Ps(%)
	B	141	93	70	---	900	---
	EAM	62	40	29	----	477	---
	ELG	69	35	20	---	406	---
Salt (NaCl)	B + 0.1 M	70	38	40	42	260	70
	B + 0.5 M	65	34	30	57	180	80
	B + 1.5 M	50	25	23	67	80	91
	EAM + 0.1 M	58	34	23	20	390	18
	EAM + 0.5 M	41	21	18	38	228	52
	EAM + 1.5 M	20	15	13	56	120	75
	ELG + 0.1 M	55	32	16	20	335	17
	ELG + 0.5 M	38	20	12	40	170	58
	ELG + 1.5 M	22	11	8	60	88	80
Lime	B + 2 %	134	88	38	45	700	21
	B + 4 %	108	59	29	58	485	65
	B + 6 %	103	53	21	70	135	85
	EAM + 2 %	53	35	20	31	286	40
	EAM + 4 %	37	22	13	56	133	72
	EAM + 6 %	24	12	9	70	81	83
	ELG + 2 %	63	23	15	25	250	37
	ELG + 4 %	32	8	12	40	80	81
	ELG + 6 %	20	6	8	60	40	90
Cement	B + 2 %	124	82	42	40	800	11
	B + 4 %	115	73	28	60	504	44
	B + 6 %	110	59	24	66	324	64
	EAM + 2 %	50	32	22	25	340	28
	EAM + 4 %	39	24	15	48	130	72
	EAM + 6 %	31	14	13	56	85	82
	ELG + 2 %	45	25	13	35	280	31
	ELG + 4 %	32	19	11	45	77	81
	ELG + 6 %	29	10	9	55	57	86

b) Combination Stabilization

The Combination soil stabilization used is the combination of lime and cement for different percentage (2% Lime + 2% Cement; 2% Lime + 6% Cement; 6% Lime + 2% Cement; 6% Lime + 6% Cement). Figure 4 shows the evolution of free swelling (G %) versus time for three soils for different types of stabilization combined. The effect of combining lime + cement on the swelling ratio is shown in Fig. 5. Reducing the rate of swelling is around 70% for a combination of 6% lime and 6% cement. In general, the action of the combination of lime and cement conduit to effects similar to those of one lime or cement alone. This result is in good agreed with those found by Al-Rawas *et al.* 2005.

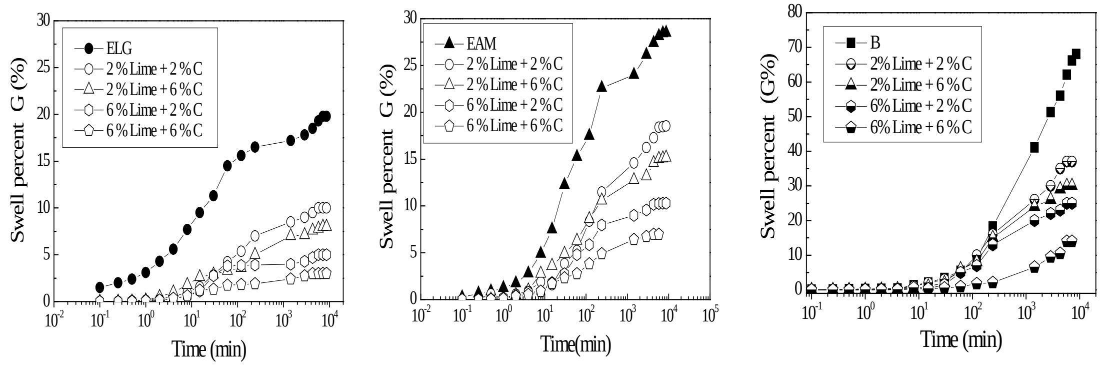

Figure 4 : Evolution of free swelling (G %) versus time for three soils with different types of stabilization Combination

A second type of Combination stabilization has been used for bentonite. It is the combination of lime and salt NaCl. The different combinations are used: 2 % Lime + 0.1 M ; 2 % Lime + 1.5 M ; 6 % Lime + 0.1 M; 6 % Lime + 1.5 M. Figure 5 shows the evolution of free swelling (G%) versus time. For a combination of 2% + 0.1 M CH, reducing the swelling rate is around 50%. For a combination of 6% Lime + 1.5 M, the reduction is about 80%. Figure 6 shows the evolution of swelling pressure versus time by the method of constant volume. For a combination of 6% Lime + 1.5 M, swelling pressure passes for 900 kPa to 50 kPa, a reduction is more than 95%. This stabilization method seems more effective in reducing the swelling pressure as the free swell.

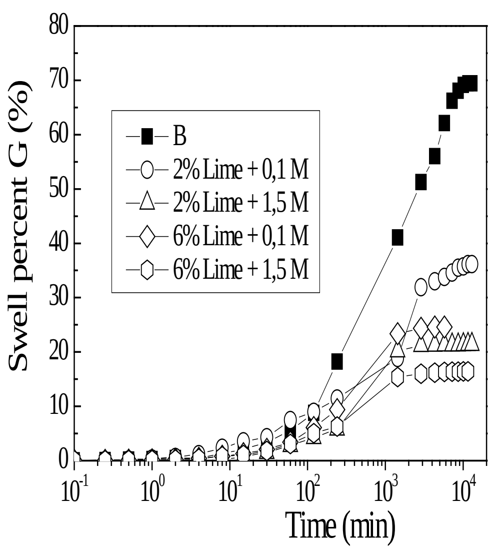

Figure 5 : Evolution of free swelling (G %) versus time for three soils with different types of stabilization Combination (lime + salt)

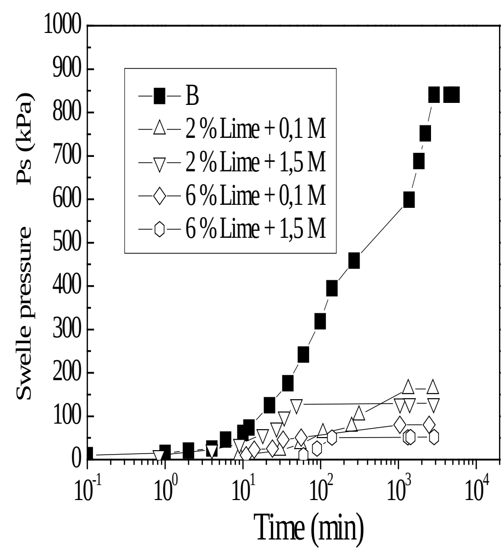

Figure 6 : Evolution of swelling pressure (Ps) versus time for three soils with different types of stabilization Combination (lime + salt)

V. Conclusions

This paper evaluated the effect of salt, lime, cement, combinations of lime and cement, and combinations of lime and salt on the swelling potential of Algeria expansive soil. Addition of lime to clay soil reduces the liquid limit, plasticity index and swelling potential. Cement stabilization is similar to that of lime and produces similar results. Chemical stabilization by saline containing NaCl seems less effective. For a 1.5 M concentration, reducing the swelling potential is less than 70%. The salts are more effective in reducing the swelling pressure as the magnitude of swelling Stabilization combined lime + cement gives satisfying results when the reduction of swelling parameters can attain 70%. The action of the combination of lime and cement conduit to effects similar to those of alone lime or cement alone. Stabilization combined lime + salt, the results is better than the combined lime + cement stabilization. For a combination of 6% lime + 1.5 M, reduction of swelling parameters is of the order of 80 for the free swell and more than 95% for the swelling pressure.

Generally, all stabilizers caused a reduction in both swell pressure and swell percent. Finally, the abundance of the two materials (lime and salt) at reasonable prices in the region. We can advance of the technique of combined stabilization (lime + salt) an alternative economical and effective for the treatment of swelling clays.

References Références Referencias

1. Aboubeker N & Sidi Mohamed A.M (2004) , "Stabilization of swelling soils using salts". *Conférence internationale de géotechnique,* Beyrouth, pp.1-6
2. Al-Rawas A.A, A.W.hago., Hilal Al-Sarmi. (2005), "Effect of lime, cement and Sarooj(artificial pozzolan) on the swelling potencial of an expansive soil from Oman". *Elsevier.Building and Environment*, **N°40**, pp.681-687.
3. Al-Rawas AA, Taha R, Nelson JD, Beit Al-Shab T, Al-Siyabi H. (2002),"A comparative evaluation of various additives used in the stabilization of expansive soils", *Geotechnical Testing Journal, GTJODJ, ASTM*, **25**(2):199–209.
4. Bekkouche A, Azzouz F.Z, Aissa Mimoune S.M, (2007), « Salt Stabilization of expansive clays from Tlemcen région, Algeria », *Col. Int .sols et matériaux à problémes*. Tunisie .9-11/02/2007, pp19-26.
5. Bell FG, (1996), "Lime stabilization of clay minerals and soils". *Engineering Geology 1996*, **42**:223–37.
6. Bental, (2002), « Projet de développement des gisements d'argile bentonitique du district de Hammam Boughrara, Maghnia, (Tlemcen), Algérie.
7. British Standard 1377, (1990)," Methods of test for soils for civil engineering purposes". *London: British Standard Institution*.
8. Chen. F.H. (1988),"Foundations on expansive soil", *Developments in Geotechnical Engineering, Vol* ***54**.* *Elsevier Publishing Co. Amsterdam*, 464 pages.
9. Gueddouda M.K, Lamara M, Aboubekr N, Goual I, (2007), "Characterization and stabilization of expansifs soils, effect dune sand and salt association for swelling potential ». *Col. Int .sols et matériaux à problèmes.* Tunisie .9-11/02/2007. pp27-34.
10. Gueddouda M.K, Lamara M, Hachichi A, Goual I, (2006), " effect dune sand for swelling potential of clays swelling" *revue technologique et scientifique .COST*. **N°4**, pp .15-22
11. Gueddouda M. K; Lamara M; Abou-bekr. N; Taibi. S, (2010), « Hydraulic behaviour of dune sand – bentonite mixtures under confining stress". *Geomechanics and Engineering*, Vol. 2, **N°. 3**, 213-227.
12. Hachichi A & Fleureau J.M. (1999), «Characterization and stabilization for swelling soils from Algeria». *Revue Française de Géotechnique*, **N° 86**, pp 37-51.
13. Holtz W.G., & Gibbs H.J. (1956), « Engineering properties of expansive soils». *Trans of ASCE,* **Vol. 121**,1956, pp . 641-679.
14. Lamara M, Gueddouda M.K, Goual I. (2005), « expansive soil stabilisation by addition dune sand région of Laghouat ». *2ème Journées d'études sur les sols gonflants. Tlemcen*. Algérie 13-14 /11/2005. pp.129-139.
15. Lamara M, Gueddouda M.K, Benabed.B. « Physical and chemical s*tabilisation of expansive soil* », *Revue Française de Géotechnique*, **N° 115**, 2006, pp 25-35.
16. Nalbantoglu Z, Gucbilmez E.(2001), « Improvement of calcareous expansive soils in semi-arid environments ». *Journal of Arid Environments* ,**47**(4):453–63.
17. Ranganatham B.V & Satyanarayana B. (1965),"A rational method of preding swelling potential for compacted expansive clays". *Proc of the 6th I.C.S.M.F.E.* Montreal.1965.
18. Sherwood PT.(1995)," Soil stabilization with cement and lime: state-ofthe- art review". *Transport Research Laboratory, London: Her Majesty's Stationery Office*; 1995. 153 p.
19. Seed H.B., Woodward R.J., Lundgren R. (1962), « Prediction of swelling potential for compacted clays ». *Journal of the soil Mechanics and foundations division. ASCE*, vol 88, N° **SM4**, pp.107-131.
20. Serratrice J..F and B.Soyez, (1996), « *test swelling* ». *laboratory of ponts et chaussées.204.Juillet–Août 19*96-réf **.4082**, pp 65-85.
21. Skempton A.W. (1953), « The collaidal activity of clays ». Proceedings of the Third *International Conférence on Soil Mechanics and Foundations Engineering*,vol.**1**,pp 57-61.
22. Sridaharan A, Rao A.S, & Sivapullaiah P.V. (1986), « Swelling pressure of clays ». *Geotech.test, J.G.T.J.D.J,* **Vol 9 N° 1**, pp. 24-33.
23. Van der Merwe DH. (1975), "Contribution to specialty session B, current theory and practice for building on expansive clays". *Proceedings of the sixth regional conference for Africa on soil mechanics and foundation engineering*, Durban, vol. **2**, p. 166–7.
24. Vijayvargiya V.N., Ghazzaly D.I,(1973)," Prediction of swelling potential for natural clays", *Proc. of the 3rd, I.C.E.S.*, Haifa, pp. 227-236.
25. Williams A.B., Donaldson G.W. (1980), « Developements related to building on expansive soils in South Africa : 1973-1980 ». *Proc. 4th Int. Conf. On Expansive Soils*, Denver, vol. **2**, 1980, pp. 834-844.

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