

## Durability of treated silty soil using lime and cement in road construction – a comparative study

Hadj Bekki<sup>\*1</sup>, Zahia Djilaili<sup>1a</sup>, Youcef Tlidji<sup>1b</sup> and Tahar H. Daouadji<sup>1c</sup>

<sup>1</sup>Department of Civil Engineering, University of Tiaret,  
BP 78, Zaâroura, Tiaret 14000, Algeria

**Abstract.** The Treatment of soils using lime and cement is one of the appropriate techniques that provides solutions for poor geotechnical soils used in road construction, as subgrade layers. The present paper consists of a comparative study of bearing and sustainability of silty soils treated with lime and/or cement. The Tests carried out on samples of treated silty soil showed a great improvement in workability and bearing capacity compared to a natural one. It was also noticed that the soil that was treated with 5% of cement, and with 1% of lime and 4% of cement gives the highest values of CBR (Californian Bearing Ratio). However, the highest durability of the treated soil was obtained by mixed treatment (1% of lime and 4% of cement), which values the mixed treatment efficiency. It should also be noted that the proposed solution fits sustainable development well.

**Keywords:** sustainability; silty soil; treatment; lime; cement; environment; road infrastructure

### 1. Introduction

The depletion of natural resources in noble materials and the increase in the costs associated with the use of these materials requires the use of local materials in geotechnical works. However, the poor geotechnical properties of these materials cause difficulties for construction projects and therefore, they must be stabilized in order to improve their properties.

Soil treatment with a hydraulic binder is one of the appropriate techniques which consists in incorporating into the soil this filler material, optionally with water, and mixing them together to obtain a homogenous material with better properties compared to the natural soil. This technique uses chemical affinities of soil and binder in order to improve the physicochemical and mechanical soil properties. Several research studies have been performed on the stabilization of clay soils using various additives like cement, lime, fly ash and silica fume (Bell 1996, Boardman et al. 2001, Kalkan & Akbulut 2004, Al-Rawas 2005, Cuisinier et al. 2011, Harichan et al. 2011, Mahamedi and Khemissa 2013, Voottipruex and Jamsawang, 2014).

Soil treatment with hydraulic binders is a very interesting solution for improving poor soils to use them in subgrade layers, embankments, and even, in foundation layers, due to the technical, economic and environmental benefits of this solution (LCPC 2000). Fine soils like clays and silts have undesirable poor properties for the use in road construction. Indeed, these soils swell in the presence of water, shrink during dryness and abound under freezing effects, which make their use very subtle (Nelson and Miller 1992). The addition of a hydraulic binder such as lime significantly modifies these materials' behavior by improving their consistency and their bearing in the short and long terms.

This soil treatment process falls in the approach of sustainable development (Evangelos and Stavridakis 2006). Indeed, the execution of the treatment is a cold working, which significantly reduces pollution and the discharge of noxious fumes into the atmosphere (an energy saving and clean technique). In addition, this

---

\*Corresponding author, Ph.D., E-mail: [abekkihadj@yahoo.fr](mailto:abekkihadj@yahoo.fr)

<sup>a</sup>Master, E-mail: [Zahoo14000@gmail.com](mailto:Zahoo14000@gmail.com)

<sup>b</sup>Ph.D. Student, E-mail: [tlidji.youcef@gmail.com](mailto:tlidji.youcef@gmail.com)

<sup>c</sup>Ph.D., E-mail: [daouadjitahar@gmail.com](mailto:daouadjitahar@gmail.com)

technique allows a significant overall energy saving by reducing materials to be transported, materials to be dumped and thus the decrease of indirect impacts, such as an inconvenience to road users and residents, and the reduction of the road network fatigue. The proposed technique represents an adequate solution for the preservation of natural resources, limiting nuisances caused by the transport of materials and reducing the cost of earthworks and the costs of landfill materials removed, which will certainly contribute to preserving the environment.

Durability that is defined as the ability of material to retain stability and integrity over years of exposure to destructive forces of weathering is one of most important factors of materials selection. However, poor soil does not sustain the effects of environmental factors, such as wetting-drying cycles, hence the interest of soil treatment (Al-Kiki et al. 2011, Estabragh and al. 2013). But treatment agents do not provide all the durability required in order to increase the life of road infrastructure; therefore in this comparative study, we tried to find out which mixture treatments that will ensure more durability; single or mixed ones.

This work presents the results of an experimental study carried out on a silty soil collected from a site located at 10 kms from Tiaret city (Algeria). It should be noted that this type of soil is found abundantly in the high plateaus of Algeria (Tellian Atlas in the north), which makes its use (valorization) very attractive in the field of road construction. This would be a good contribution towards sustainable development.

This paper aims at determining which mixture treatment will give the best durability of this silty soil in subgrade layers and embankments. We present, firstly, the identification tests of the studied soil, then the study of the influence of the treatment on the improving of the mechanical and physicochemical properties of the treated soil and, finally, the sustainability tests conducted on soil samples treated with various dosages of lime and/or cement.

## 2. Technical soil treatment

Soil improvement methods are one of the tools available for engineers to solve soil stability problems or soil deformations during project development. Many techniques have been developed by geotechnical engineers in the 20<sup>th</sup> century. They help to improve the soils' geotechnical characteristics and mechanical properties. Some of these are old, like soil treatment with lime or cement, while others are more recent, such as mixed treatment (Bell 1996, CRR 2004b, Estabragh et al. 2013). For two decades, they have witnessed considerable improvement and are now used in a very broad way in road projects.

### 2.1 Treatment with lime

The interactions of lime with the soil particles can be described by a series of complex physical and chemical processes that affect the mechanical behavior of soils. Generally, there are two effects during lime treatment (Bell 1993, Muntohar and Hantoro 2000, CRR 2004a). At first, there is a so-called short-term or immediate effect, which occurs in the following hours of the contact between the lime and the soil and leads to flocculation / agglomeration of the soil particles. This results in a change in the texture of the soil. In a second step, there is an effect, said to be long-term, in which pozzolanic reactions occur. These reactions, which take place in the presence of water, between the lime and compounds composed of silicon and / or aluminum, lead to the formation of pozzolanic compounds that develop through time.

### 2.2 Treatment with cement

The cement quickly hardens the soil irreversibly, but if there will be rupture of soil treated (mechanical action) there is no new cement reaction. Cement setting is faster than lime (which is still evolving after a year), but it is stopped by frost (Ghembaza et al. 2012).

There are several similarities between lime and cement as stabilizers (Bahar et al. 2004, Al-Rawas 2005), some distinctions must be identified before making a choice. These differences include the durability and permanence of the effects of treatment, initial resistance, the development of resistance as a function of time and curing time (Little et al. 2000). The treatment efficiency depends on the quantity of cement used and the type of soil (Evangelos and Stavridakis 2006). Studies have shown that clayey materials with low plasticity indexes are better suited to be stabilized with cement (Muhunthan and Sariosseiri 2008).

2.2 Combined treatment (lime-cement)

In the case of wet soil, lime is recommended and for low-clay, cement is recommended. For the combined treatment, lime is used firstly at low rates (0.5 to 2%) and thereafter, we add cement, because these binders have a complementary action (Morel, 1984).

The lime pretreatment, by its immediate action, brings the soil to an optimal state for its treatment with cement (DAAF 1994) which is due to a microstructural organization (Lemaire et al. 2013).

3. Materials

3.1 Soil

The soil used in this study is a silty soil obtained from a deposit called Sidi El-Abed which is situated to the east of Tiaret city (Algeria). Some of the soil index properties and chemical tests are presented in Table 1.

According to the road earthworks guide (LCPC 1992), the soil is classified as A1 class and subclass A1ts (low plastic silt).

3.2 Lime

The lime was brought from Saida factory (Algeria). The main physical and chemical properties of lime are presented in Table 2.

3.2 Cement

The cement was brought from Chlef factory (Algeria). It is a Portland cement class; CPJ-CEM II/ A 42,5. It consists principally of Clinker Portland (80 to 90%), pure calcareous (6 to 20 %) and secondary components (0 to 5% of calcium as a setting regulator). The main physical and chemical characteristics of cement are summarized in Table 3.

Table 1 Main physical and chemical properties of natural soil

Value of Dmax (mm)	Sieved over #80 sieve	Natural water content (wnat)	WOPM (%)	Plasticity Index Ip	VBS*	Carbonate rate
31,5	39 %	6,32 %	10.82	13,15	1,0 %	82 %

\*VBS: Methylene blue value

Table 2 Main physical and chemical properties of lime

CaO (%)	MgO (%)	Fe <sub>2</sub> O <sub>3</sub> (%)	Al <sub>2</sub> O <sub>3</sub> (%)	SiO <sub>2</sub> (%)	SO <sub>3</sub> (%)	Na <sub>2</sub> O (%)
> 73.3	<0.5	<2	<1.5	<2.5	<0.5	0.4-0.5
CO <sub>2</sub>	CaCO <sub>3</sub>	Specific Density (g/cm <sup>3</sup> )	Over 90 μm (%)	Over 630 μm (%)	Insoluble material (%)	Apparent density (g/l)
<5	<10	2	<10	0	<1	600-900

Table 3 Main physical and chemical characteristics of cement

SO3 (%)	Cl (%)	Initial setting	Heat stability	Shrinkage at 28 days	Min Compressive strength	Max Compressive strength
≤ 2	≤ 0.08	> 60min	<7mm	<650µm/m	42,5 N/mm <sup>2</sup>	62,5 N/mm <sup>2</sup>

#### 4. Methodology

##### 4.1 Consistency and bearing tests performed on treated and natural soil

The soil studied was treated by adding of 3 and 5% of lime (S+3L and S+5L). The same percentages were applied to the soil treated with cement (S+3C and S+5C) in order to compare the results of binder effects. However, for the mixed treatment, the lime was added firstly at a percentage of 1% (pretreatment) and then 2 and 4% of cement was added to the soil (S+1L+2C and S+1L+4C).

The experiments were conducted to determine the Atterberg's limits, compaction characteristics and California Bearing Ratio (CBR). The tests were carried out according to European and French test standards (AFNOR 1993, 1999, 1997).

##### 4.2 Durability tests performed on treated soil

The durability test is used to ensure the sustainability of the soil. The test is conducted according to an ASTM standard test method D 559-96 (ASTM 1996). The latter covers procedures for determining losses in the soil-binder, water content changes and volume changes (swelling and shrinkage) produced by repeated wetting and drying of soil-cement specimens.

These test methods are applied to soil treated with cement, but it can be generalized for other soil-binders, such as soil treated with lime.

Samples were prepared with varying binder contents. A set of two specimens were prepared for each mixture. These specimens were compacted at the optimum moisture content obtained from the Proctor compaction test. The test requires measurements and samples handling for each cycle of wetting and drying procedures over 24 days.

#### 5. Results and discussion

The change in the plasticity index in terms of the percentage of lime and cement is shown in Fig. 1. It was noted that there is a decrease in the plasticity index when the binder content increases. Indeed, adding lime to the soil develops an agglomeration of fine clay particles into crumbly coarse ones (flocculation of clay) and therefore, a reduction in the plasticity index (Estabragh et al. 2013). The same tendency was observed when the cement was added into the soil, which is due to cementitious links between the calcium silicate and aluminate hydration products and the soil particles (Bahar et al. 2004, Estabragh et al. 2013, Phanikumar et al. 2014). It was found that mixed treatment significantly reduces the plasticity index compared to single treatment (with cement or lime). The same result was obtained by Khemissa and Mahamedi (2014) for expansive clay treated with 4% of lime and 8% of cement.

Adding binders to the soil renders it less sensitive to water and modifies its consistency and therefore, allows an improvement in the soil workability characteristics by the effect of cementing and pozzolanic reactions.

Fig. 2 shows compaction curves for various soil and mixtures obtained from the Proctor test. It can be observed that the addition of binders increases the optimum moisture content of the soil proportionally with the percentage of treating agent, because this latter needs a supplementary quantity of water. The optimum dry density for treated soil with a single binder is less than that for untreated soil. However, for the mixed treatment, the optimum dry density is greater than that for natural soil, which can be explained by the fact that the pretreatment limits the volume change of the soil.

For the soil treated with lime, the dry density increases with the increase in the percentage of lime, which can be justified by the fact that flocculated particles might be collapsed under compaction and therefore, causing an increase in dry density. However, for the soil treated with cement, the dry density decreases with the increase in the amount of cement.

California Bearing Ratio (CBR) results of soil and mixtures obtained with a high compaction effort are presented in Fig. 3. It was noted that the cement modification is more efficient than the lime modification in CBR results. The maximum CBR is obtained for the mixed treatment with 1% of lime and 4% of cement, which confirms the result obtained for the plasticity index (Khemissa and Mahamedi 2014).

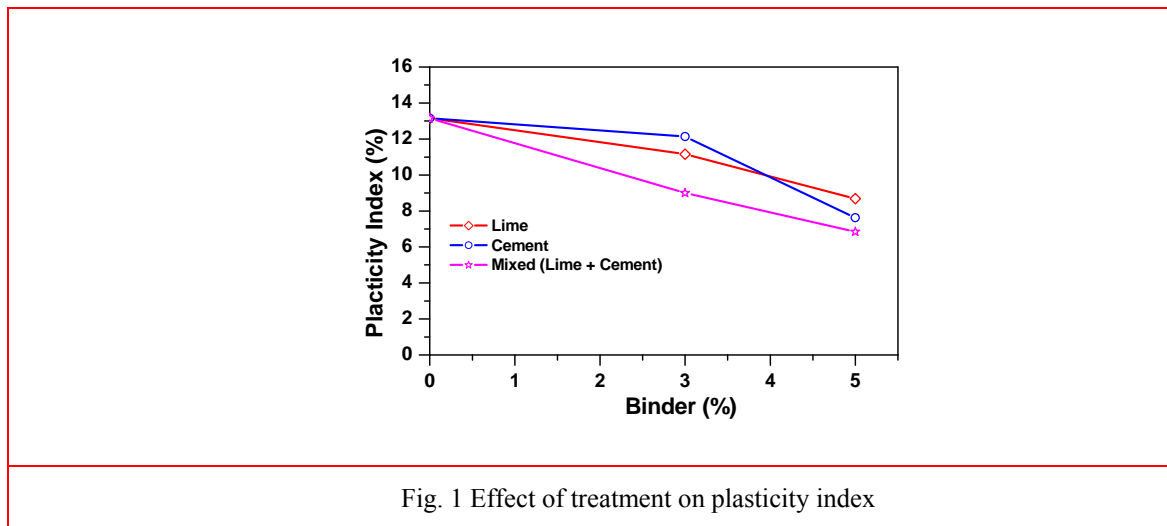


Fig. 1 Effect of treatment on plasticity index

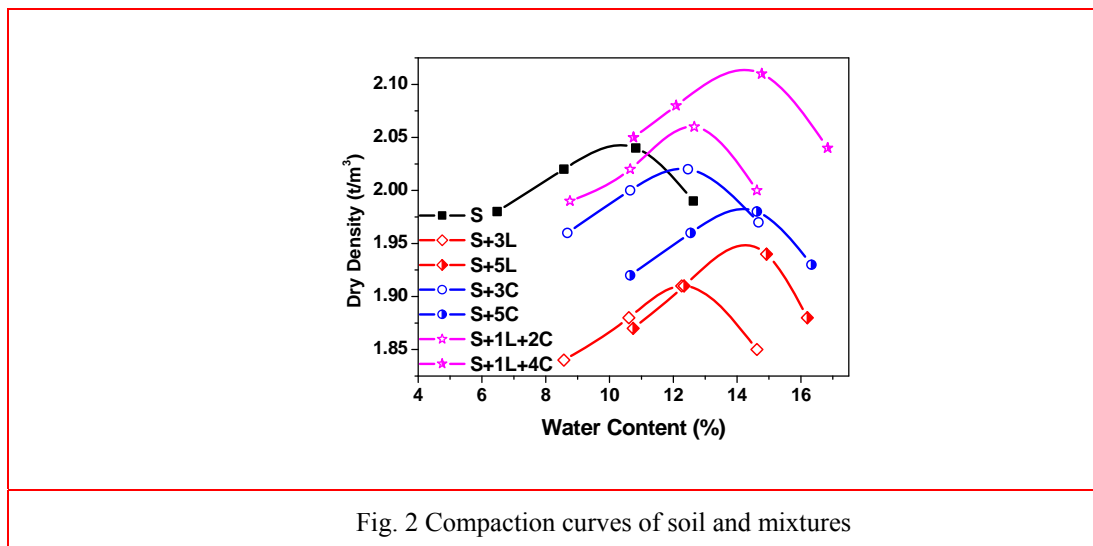


Fig. 2 Compaction curves of soil and mixtures

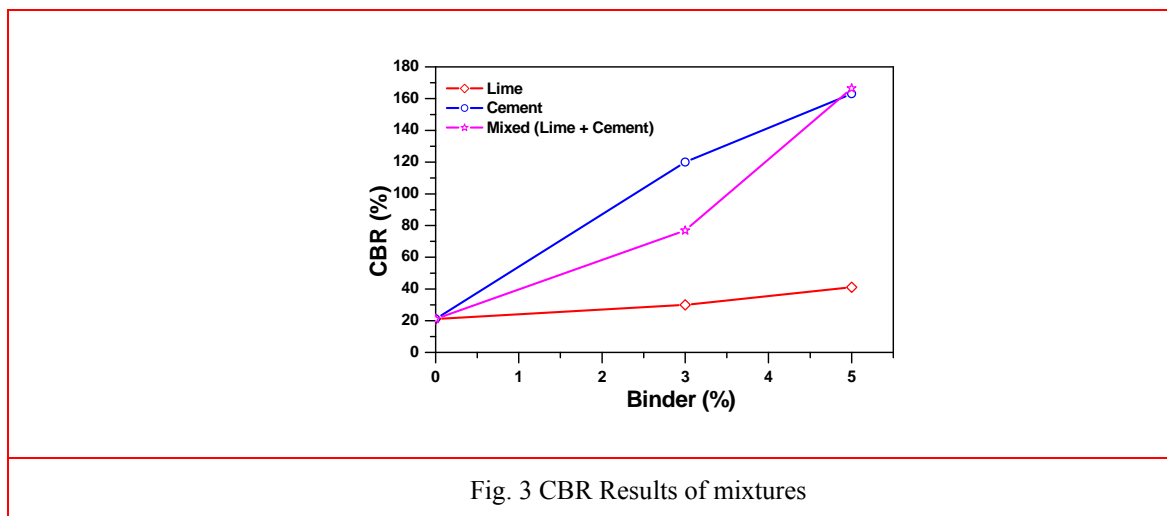


Fig. 3 CBR Results of mixtures

Fig. 4 shows the results of the durability test performed on various mixtures. It can be observed from the graph that the maximum percentage weight loss was obtained for soil treated with 3% of lime, which is about 30%, because lime has a limited effect to prevent shrinkage (Stoltz and al. 2012). The least weight loss was obtained for the mixed treatment with 1% of lime plus 4% of cement. It seems that soil treated with lime or with a small amount of cement presents no resistance for durability, as the percentage weight loss exceeds 10%. Such a threshold is fixed for silty soil by the Canadian Portland Association (Noor Megat 1994). Thus, the mixed treatment with 1% of lime and 4% of cement is the only mixture which satisfied the durability requirements. Nevertheless, the soil treated with 5% of cement presents a weight loss situated on the edge of the threshold, although the cement has a good reputation for having a good resistance against wet-dry cycling tests. Filippo and Puppala (2012) concluded in their study performed on the treatment of plastic clay with lime and cement that the combined treatment emerges as a strategy for improving the immediate performance of the treated soil. Furthermore, Nagaraj et al. (2014) found that the mixture with lime and cement offers a high strength in the long-term of compressed stabilized Earth Blocks (CSEBs). This confirms the effectiveness of the combined treatment. Indeed, the addition of lime at a rate of 1% may be a sufficient quantity to lead to an increase in the pH of the mixture and allows one to stimulate pozzolanic reactions by adding up to 4% of cement, which contributes to the strengthens of the treated soil by the self hydration of the cement.

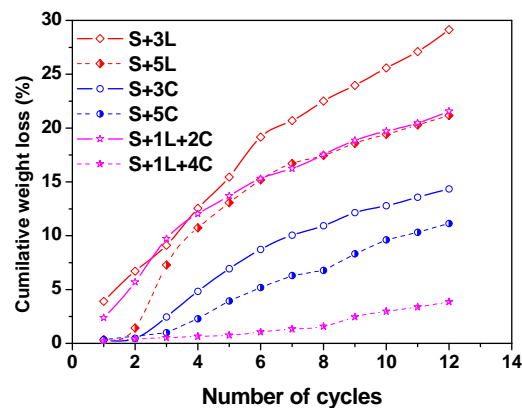


Fig. 4 Wetting and drying test on several mixtures

It can be concluded that the addition of lime or a small amount of cement slightly influenced durability resistance, while an additional amount of cement will lead to a significant decrease in weight loss and therefore, a good sustainable resistance of pavement layers prepared within the combined treatment of silty soil.

## 6. Conclusions

This paper aimed to study the durability of a silty soil treated with cement and lime for its valorization in embankments or subgrade layers using a technical process which fits sustainable development. Choosing this silty soil is justified by its processability, on the one hand, and its abundance, on the other.

It was found that the treatment of the soil with lime and/or cement significantly modifies the consistency of the soil and improves its workability characteristics. However, cement modification is more efficient than lime modification in improving CBR. It was also noted that the combined-agent treatment with 1% of lime and 4% of cement gave the greatest CBR.

Furthermore, it was concluded that to ensure durability of pavement layers performed with treated silty soil, it may be preferable to opt for a mixed treatment with lime at a low rate (around 1%) and cement at relatively higher rates (around 5%).

## Acknowledgments

The work presented in this paper was carried out with the support of the research project PNR-Treatment and improvement of soils with lime.

## References

- AFNOR (1993), *Détermination des limites d'Atterberg. Limite de liquidité à la coupelle– Limite de plasticité au rouleau*, Norme NF P 94-051, France.
- AFNOR (1999), *Essai Proctor normal – Essai Proctor modifié*, Norme NF P 94- 093, France.
- AFNOR (1997), *Indice CBR après immersion – Indice portant immédiat*, Norme NF P94-07, France.



- Al-Kiki, I.M., Al-Atalla, M.A. and Al-Zubaydi, A.H. (2011), "Long Term Strength and Durability of Clayey Soil Stabilized With Lime", *Eng. & Tech. Journal*, **29** (4), 725-735.
- Al-Rawas, A.A., Hugo, A.W. and Al-Sami, H. (2005), "Effect of lime, cement and artificial pozzolan on the swelling potential of an expansive soil from Oman", *Building & Environment*, **40**, Elsevier, 267-281.
- ASTM (1996), *Standard test methods for wetting and drying compacted soil-cement mixtures*, Norm ASTM D 559 – 96, USA.
- Bahar, R., Benazzouz, M. and Kenai, S. (2004). "Performance of compacted cement stabilized soil", *Cement and Concrete Composites*, **26**, 811-820.
- Bell, F.G. (1993). "Engineering Treatment of Soils", London: Chapman and Hall, UK.
- Bell, F.G. (1996), "Lime stabilization of clay minerals and soils", *Eng. Geol.*, **42**(4), 223-237.
- Boardman, D.I., Glendinning, S. and Rogers, C.D.F. (2001). "Development of stabilization and solidification in lime-clay mixes", *Geotechnique*, **51**(6), 533-543.
- CRR 'Centre de recherches routières - Belgique' (2004a), "Code de Bonne Pratique Pour le Traitement des Sols à la Chaux et/ou Ciment - Recommandations Pour le Recyclage des Terres", CRR, Belgique.
- CRR 'Centre de recherches routières- Belgique' (2004b), "Amélioration des Sols Pour Terrassements et Fond de Coffre, Complément au Code de Bonne Pratique", CRR, Belgique.
- Cuisinier, O., Auriol, J-C., Le Borgne, T. and Deneele, D. (2011), "Microstructure and hydraulic conductivity of a compacted lime-treated soil", *Eng. Geol.*, **123**(3), 187-193.
- DAAF 'Departments of the Army and Air Force' (1994), "Technical manual", **5-822-14**, Washington, USA.
- Estabragh, A.R., Pereshkafti, M.R.S., Prasaei, B. and Javadi, A.A. (2013). "Stabilized expansive soil behaviour during wetting and drying". *Intern. J. of Pavement Eng.*, **14**(4), 418-427.
- Evangelos, I.S. (2006). "A solution to the problem of predicting the suitability of silty-clayey materials for cement-stabilization", *Geot. and Geol. Eng.*, **24**, 379-398.
- Ghembaza, M.S., Dadouch M. and Bellia, Z. (2012), "Effet du ciment sur le comportement physico-chimique d'un matériau de la région de Sidi Bel Abbès", *Proceedings of 30<sup>th</sup> meeting of AUGC/IBPSA, Chambéry, France*, 6-8 juin, **1**, 1-10.
- Harichan K, Ghrici M, Khebizi W. and Missoum, H. (2011), "Effet de la combinaison de la chaux et de la pouzzolane naturelle sur la durabilité des sols argileux", *Proceedings of 29<sup>th</sup> meeting of AUGC-Tlemcen, Algeria*, 29-31 mai, **2**, 65-75.
- Kalkan, E. and Akbulut, S. (2004), "The positive effects of silica fume on the permeability, swelling pressure and compressive strength of natural clay liners", *Eng. Geol.*, **73**(1-2), 145-156.
- Khemissa, M. & Mahamedi, A. (2014), "Cement and lime mixture stabilization of an expansive overconsolidated clay", *Applied Clay Science*, **95**, 104-110.
- LCPC 'Laboratoire Central des Ponts et Chaussées-SETRA- France' (1992), "Guide des Terrassements Routiers, réalisation des remblais et des couches de forme", LCPC, France.
- LCPC 'Laboratoire Central des Ponts et Chaussées-SETRA-France' (2000), "Guide Technique", LCPC, France.
- Lemaire, K., Deneele, D., Bonnet, S. and Legret, M. (2013), "Effects of lime and cement treatment on the physicochemical, microstructural and mechanical characteristics of a plastic silt", *Engineering Geology*, **166**, 255-261.
- Little, D.N., Males E.H., Prusinski, J.R. and Stewart, B. (2000), "Cementitious Stabilization", Committee on Cementitious stabilization, TRB, National Research Council Washington, USA.
- Mahamedi, A. and Khemissa, M. (2013), "Cement stabilization of compacted expansive clay", *Online j. Sci. Technol.*, **3**(1), 33-38.
- Muhunthan, B. & Sariosseiri, F. (2008), "Interpretation of Geotechnical Properties of Cement Treated Soils", WSDOT Research Report", WA-RD 715.1, Washington State Department of Transportation, USA.
- Muntohar, A.S. and Hantoro, G. (2000), "Influence of rice husk ash and lime on engineering properties of clayey



- subgrade”, *Electronic Journal of Geotechnical Engineering*, 5.
- Morel, G. (1984), “Étude en laboratoire du traitement à la chaux et au ciment des sols fins”, *Bulletin de liaison du Labo P. et Ch.*, **133**, 63-70.
- Nagaraj, H.B., Sravan, M.V., Arun, T.G. and Jagadish, K.S. (2014), “Role of lime with cement in long- term strength of Compressed Stabilized Earth Blocks”, *International Journal of Sustainable Built Environment, Article in Press*.
- Nilson, J.D. and Miller, R.D. (1992), “*Expansive Soils: Problems and Practice in Foundation and Pavement Engineering*”, New York: John Wiley and Sons, USA.
- Noor Megat J.M.L. (1994), “Durability and strength characteristics of cement stabilized modified Melaka series”, *Journal of Islamic Academy of sciences*, **7** (2), 137-141.
- Phanikumar, B.R., Sreedharan, R. and Aniruddh, C. (2014), “Swell-compressibility characteristics of lime-blended and cement-blended expansive clays - A comparative study”, *Geomechanics and Geoengineering: An International Journal*, 1-10.
- Pratico, F.G. and Puppala, A.J. (2012), “Lime and cement treatments of subgrades in southern Italy: Facing interports Issues and challenges”, *Procedia Social and Behavioral Sciences, Italy*, **53**, 389-398.
- Stoltz, G., Cuisinier, O. and Masrouri, F. (2012), “Multi-scale analysis of the swelling and shrinkage of a lime-treated expansive clayey soil”, *Applied Clay Science*, **61**, 44-51.
- Voottipruex, P. and Jamsawang, P. (2014), "Characteristics of expansive soils improved with cement and fly ash in Northern Thailand", *Geomechanics and Engineering An Int'l Journal*, **6** (5), 437-453.