Stabilisation of Weathered Marls using Lime or Cement

Khaled Grine and Imelhain Assia
Civil Engineering Department, Saad Dahlab University, Blida (Algeria)

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ABSTRACT
The article deals with an experimental study on weathered marls from the surrounding area of Algiers, in order to investigate their stabilisation using additives in small proportion consisting principally of lime or cement. The results show that the physical parameters such as plasticity and volume changes are greatly reduced after addition of a small proportion of lime or cement. The compressibility tests show that lime and cement affect the soil in the way that they increase its stiffness. However, the strength parameters such as (CBR) and (UCS) values are greatly enhanced after addition of an amount of lime or cement. Comparison between the stabilising effect of lime and cement treatment on the weathered marls used for this investigation show that lime has better effects than cement on the stabilisation of such soils.

RÉSUMÉ
Cet article présente une étude expérimentale effectuée sur des marnes altérées, provenant d'un site situé aux alentours de la capitale Alger, afin d'investigué leur stabilisation en utilisant un faible pourcentage d'additives, principalement de la chaux ou du ciment. Les résultats montrent, que les propriétés physiques comme l'indice de plasticité, de retrais et de gonflement sont considérablement réduis après addition d'une petite quantité de chaux ou de ciment. Les testes de compressibilité montrent que la chaux ainsi que le ciment affectent le sol dans le sens ou ils augmentent sa rigidité. D'autre part, il a été noté que les propriétés mécaniques telles que le (CBR) et la résistance à la compression non confiné (UCS) des marnes augmentent de façon considérable. La comparaison entre l'effet de la chaux et celui du ciment sur la stabilisation des marnes altérées utilisées dans cette étude montre, que la chaux a plus d'effet que le ciment sur la stabilisation de tels sols.

1 INTRODUCTION

Marls are fine coherent marine sedimentary deposits, consisting mainly from a mixture of clay and calcium carbonate ($CaCo_3$), in a proportion varying from 30% to 70%. They cover an extensive area of the east, south east and west of Algiers on which much of the urban development is taking place. The main marls unit can be more than 200 m thick forming generally a homogeneous massive substratum. Their behaviour depends on the amount of carbonate and the type of the clay minerals content. Functions of the intensity of weathering, the marls are classified in three categories. From the bottom to the tope:

- Intact marls
- Intermediate marls
- weathered marls

Weathering affects generally the top part of Marley formations to a maximal depth of 5 to 6 m. The geotechnical studies of such soils have shown that the marls are fine grained soils with low permeability, low strength (when weathered), containing a significant amount of montmorillonite increasing in the weathered horizons, illite and varying proportion of smectite. The mineralogical content make the weathered marls very sensitive to water, which in most cases result in a high volume changes (swelling, shrinkage) and loss in strength which makes these formations very instable. This instability does affect structures constructed on such formations where wide tension crakes can be observed upon them as a result. It also leads to slop instability when the gradient of the slope is greater than 10%, Figure 1, Imelhaine (2009). Indeed, many attempts to build on Marley soils around Algiers have indicated many soil instabilities occurrence with significant financial consequences.

Figure1. Cracks on structure and walking path degradation duo to soil movement within Marley soils (West of Algiers)

Previous studies on soil treatments have shown that additives such as lime mainly for clayey soils and cement for coarser ones have been used successfully to enhance strength, reduce volume changes and consequently stabilise the soil. This is known as soil stabilisation. Lime stabilisation is achieved with calcium oxide (quick lime) or calcium hydroxide (hydrated lime). Cement stabilisation is often achieved by using ordinary Portland cement (OPC). In the case of lime stabilisation, the stabilisation effect depends on the reaction between lime and the clay minerals. The main effects of these reaction are, an increase in the shear strength and bearing capacity of the soil, a reduction in the susceptibility to swelling and shrinkage, a reduction in the moisture content and improvement of workability and compaction characteristics (Bell (1976, 1988 (a), 1988 (b), 1993,1994, 1996); Mitchell (1976); Bergado et al. 1996; Rogers and Glendinning (1996, 1997)).

The aim of this study is to investigate the stabilisation of weathered marls using mainly lime as they are fine clayey soils and cement for comparison, in order to reduce their volume changes and enhance their strength. For this purpose a laboratory study involving physical and mechanical tests has been conducted on weathered marls and weathered marls mixed with different proportion by weight of lime /or cement. The principal results and conclusions are presented below.

2 EXPERIMENTAL PROCEDURES

Samples of weathered marls have been obtained from a site located west of Algiers, (Cheraga) within the Plaisancian marls formation. The particle size distribution curve of the soil is given in Figure 2.

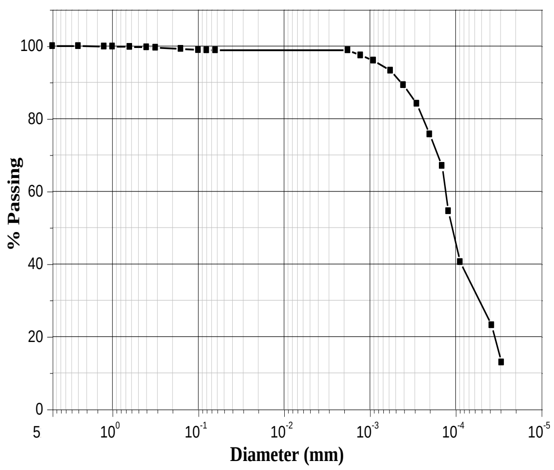


Figure 2. Particles size distribution curve

Quicklime and Ordinary Portland Cement (OPC) have been used as additives at the proportion of 2%, 4% and 8% to the weathered marls (base soil) to form mixed samples. The base soil and the additives were mixed by hand in a container to form homogenised mixed samples prior to testing. Mixed samples for unconfined compressive strength (UCS) tests were mixed with the required optimum water content (12%-18%), sealed with plastic sheet and left to cure for a week in a humidity room before testing. The falling cone aperture was used to determine the liquid limit of the base and the mixed soil with lime or cement. Shrinkage limits have been determined on homogenised base soil mass and soil mixed with 4% and 8% of lime. Oedometer and (UCS) tests using triaxial apparatus, CBR and Proctor tests, have been used respectively to perform compressibility, compression resistance, and compaction tests on base and mixed soil samples with different proportion of lime or cement.

3 RESULTS ANALYSIS

3 .1 Particles size distribution and chemical tests

Particles size distribution curve of the base soil given in (Figure 2) shows that more than 50% of the soil is less than 80 micron; this classifies the soil as fine soil. The percentage of organic matter within the soil (3%), classifies it as a non-organic soil, according to the French standard (XP P 94-011). However, the results given for the percentage of the calcium carbonate content (37.8%), classifies the soil as marls, according to the French standard (XP P 94-048).

3.2 Atterberg limits

Variation of the plastic, liquid and plasticity index function on the percentage of lime or cement added are given in Figure 3.

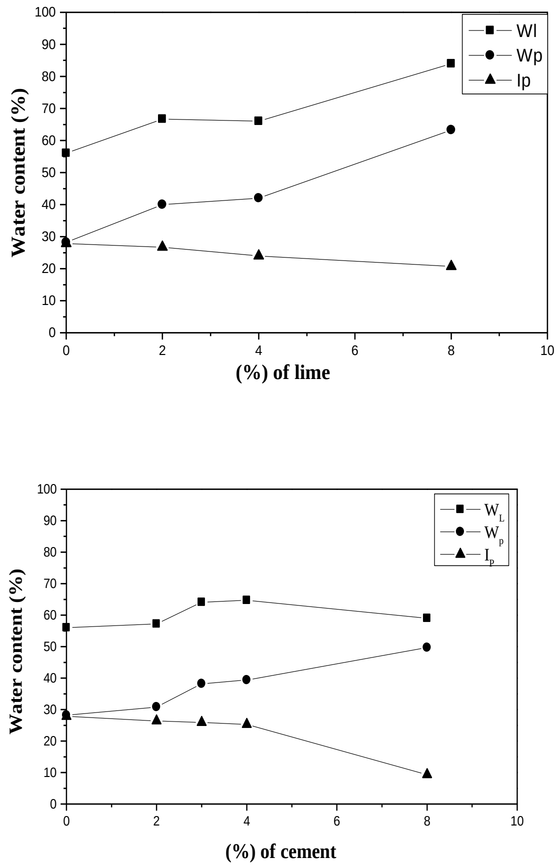


Figure 3. Variation of liquid limit, plastic limit and plasticity index function of the % of lime or cement

As can be seen from the graphs, the plastic and the liquid limit increase with increasing the amount of lime or cement within the soil mixture. This leads to a decrease in the plasticity index of the soil for all the samples tested. Decrease in the plasticity index is due to some mechanisms occurring at the surface of clay particles after addition of lime or cement. The double layer surrounding the clay particle consists of a compact layer of positive charges and a diffuse layer. The thickness of the double layer depends on the surface charge of the clay which is negative. By addition of lime or cement, and more precisely Ca^{++} cations, a cationic exchange occurs leading to a replacement of low valence cations presents within the clay particles by the Ca^{++} cations, resulting in a reduction in the thickness of the double layer. This reduces the distance between the clay particles inducing their agglomeration and flocculation. As a result of this cations exchanges and flocculation, the plasticity of the soil is reduced, (Bell (1996); Bergado et al. (1996)).

On the other hand, the effect of lime on the shrinkage limit of the weathered marls is given in Figure 4. There is an increase in shrinkage limit with increasing the amount of lime, reflecting the diminution in the volume variation by shrinkage after addition of lime.

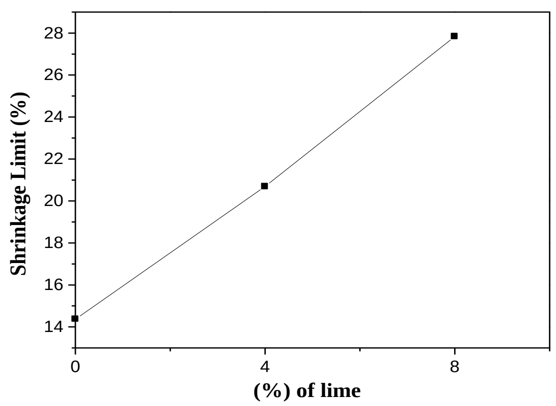


Figure 4. Effect of the addition of lime on the shrinkage of weathered marls

3. 3 Compressibility behaviour

Results from the Oedometer tests on the base soil and the one treated with 4% of lime or cement are given in Figure 5.

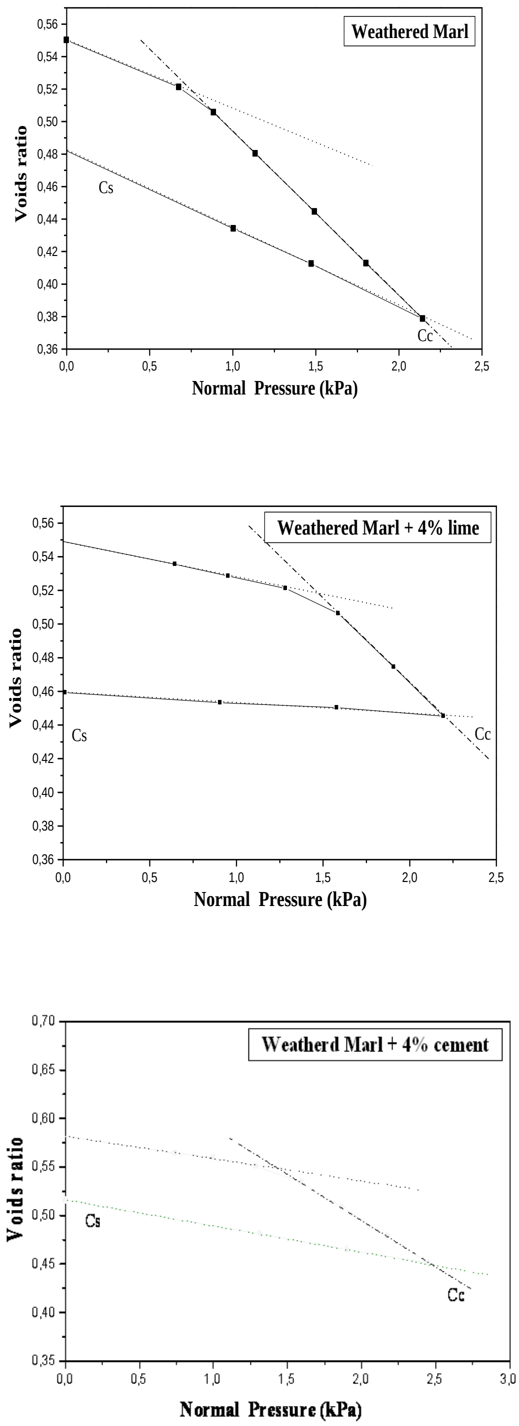


Figure 5. Effect of lime and cement on the compressibility of weathered marls

Addition of an amount of lime or cement leads to the compression curves to flatten out showing a movement to the right with a clear yield point, corresponding to an apparent pre-consolidation pressure (Pc). The treated samples seem to show greater value of (Pc) compared to the untreated ones, even though, the samples have been compacted manually under the same pressure. This is mainly due to the stiffness gained from a development of cementing bounds. This stiffness is obvious when comparing the (Cs) value of the untreated samples with the treated ones. The latest are showing lower values. However, for the compressibility index (Cc) the difference in value is not much pronounced. Values of compression index (Cc), the swelling index (Cs) and the apparent pre-consolidation pressure (Pc) for both untreated and treated samples are given in Table 1.

Table 1.Compresibilty parameters

Samples	Cc	Cs	Pc (kPa)
Weathered marl	0.14	0.045	5.82
Weathered marl + 4% lime	0.11	0.006	29.6
Weathered marl + 4% cement	0.09	0.015	27.4

3. 4 Compaction behaviour

The Proctor tests on the weathered marls samples mixed with different proportion of lime or cement are presented in Figure 6.

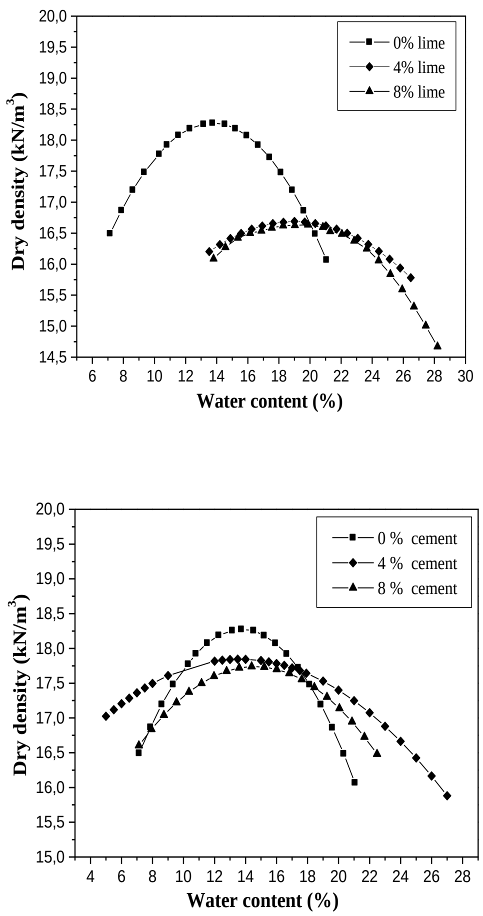


Figure 6. Effect of lime and cement on compaction caracteristics of weathered marls

The compaction curves show that the addition of lime or cement leads to an increase in the optimum water content and a decrease in dry density of the treated soil for the same energy of compaction. These changes are mainly due to the chemical reaction occurring after addition of lime or cement which request additional amount of water compared to the untreated soil, resulting in an increase in the optimum water content. However, the reduction in the dry density is more attributed to the formation of cementing products (at early age) which will affect the state of compaction of the treated soil. These modifications should not be considered as an inconvenient. Indeed, they indicate more that the lime and the cement have really reacted with the base soil and with times, an increase in the strength will be achieved.

3.5 Strength

3.5.1 CBR Results

Results from CBR tests on the base soil and the base soil treated with different proportions of lime or cement, compacted at the optimum moisture content and then soaked for a period of 4 days before testing are presented in Figure 7.

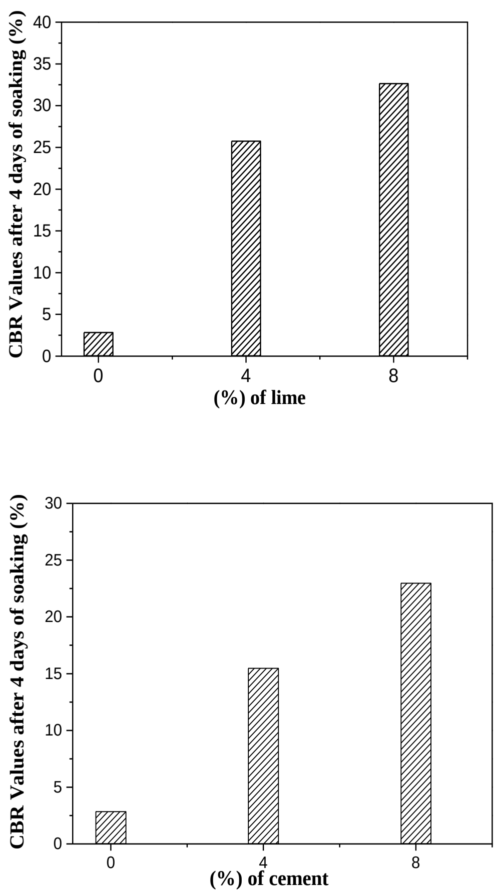


Figure 7. Effect of addition of lime or cement on CBR values of treated weathered marls

Values of the swelling potential versus the amount of lime or cement added to the base soil are given in Figure 8.

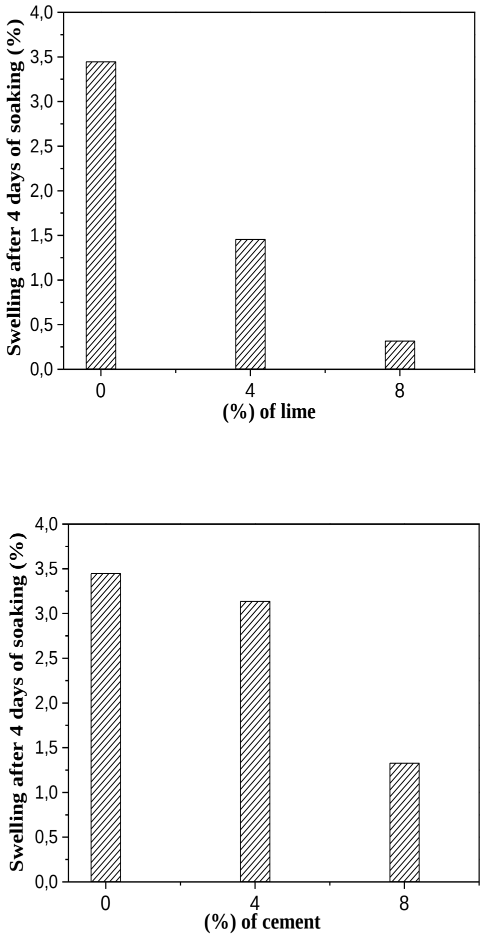


Figure 8. Effect of addition of lime or cement on swelling potential of treated weathered marls

The graphs show that CBR values of the treated soil increase with increasing lime or cement within the soil mixture. However, the swelling potential of the soil show an opposite trend. These changes are mainly due the formation of cementing products, reducing consequently the sensibility of the treated soil to water as the void ratio is reduced and increasing its strength and its stiffness.

3.5.2 UCS Results

UCS test results on untreated and treated samples with 4%, and 8% of lime or cement, compacted at the optimum moisture content, cured for 7 days at a temperature of 40^o, and the (24 hours) soaked samples before testing are given in Figure 9.

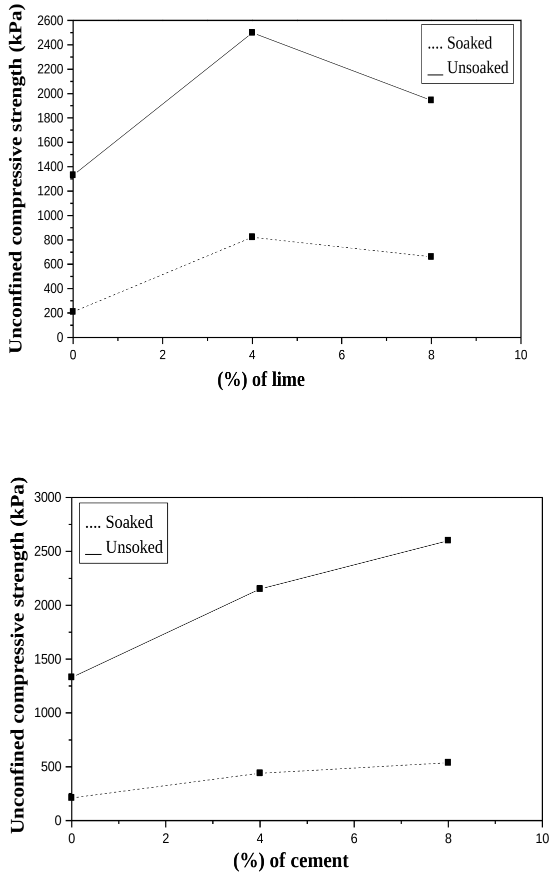
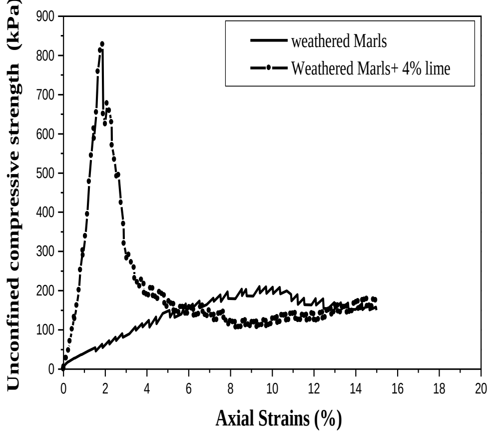


Figure 9. Effect of lime and cement on unconfined compressive strength of weathered marls

The results show a non linear trend of the unconfined compressive strength function of the amount of lime added. The unconfined compressive strength for lime treated samples increases till an optimum value then decreases. Indeed, from a certain value (optimal value), 4% in this case, there is no gain in strength. On the other hand, a linear trend function of the amount of cement added to the soil is obvious for weathered marls treated with cement. The strength increases as the amount of cement increases within the soil. These results are conforming to those reported in the literature. The gain in strength is mainly due to the pozolanic reaction resulting in cementing components which give more stiffness and strength to the treated soil. However, the fact that the trend for the increase in strength is not linear with increasing lime content as it is the case for cement, is explained mainly by the characteristics of the lime itself which does not posses any cohesion or an appreciable friction angle, Bell (1993).

Soaked samples, show similar trend function of the amount of lime or cement added compared to the compacted cured samples tested without soaking, but with lower values in strength. For treated samples, this can be explained mainly by the alteration of part of the cementation component when soaked.

Concerning the behaviour during UCS tests, previous studies on treated clayey soils have reported that the soils show a change in their behaviour after treatment with additives such as lime or cement. The treated samples tend to show more brittle behaviour, Bell (1994). This fact is well illustrated in Figure 10 representing the behaviour of treated weathered marls comparing to the untreated ones during the unconfined compressive strength test.



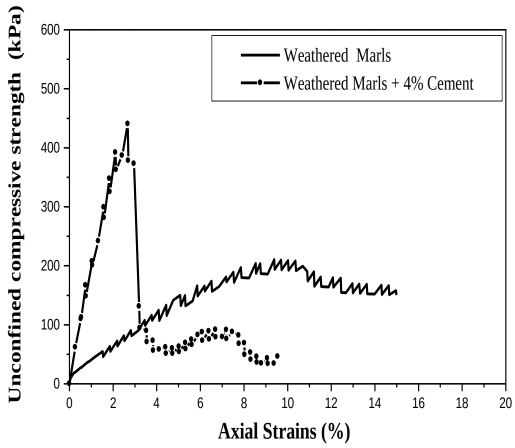


Figure 10. Effect of additives (lime or cement) on stress-strain behaviour of weathered marls

3.6 Comparison between the efficiency of lime and cement on the treatment of the weathered marls

In order to assess which of the two additives (lime or cement) is more efficient to treat the weathered marls investigated in this study, a comparison between the short term and long term performance of the treated weathered marls with either lime or cement has been established.

3.6.1 Plasticity and volume changes

Graphs 11 (a) shows the variation of the plasticity index values versus the percentage of lime or cement. In Figure 11 (b), are represented the values of the swelling rate in percent versus the percentage of the additives (lime and cement). From these results, it can be clearly seen that lime reacts better with the weathered marls and hence, has more effects on reducing the plasticity and controlling the volume changes of such soils than cement do**.**

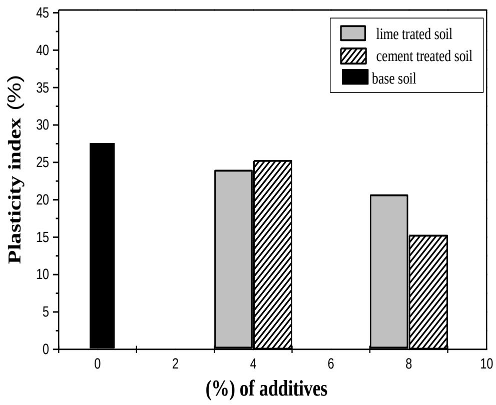


Figure 11.a Effeciency of lime and cement upon plasticity reduction for weathered marls

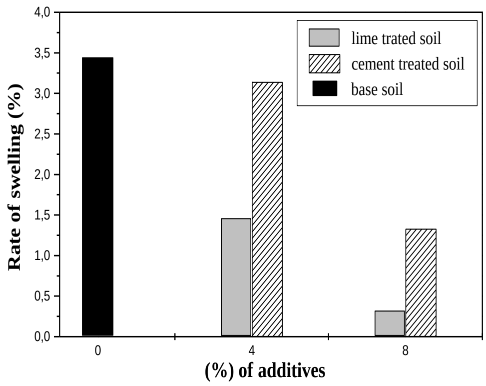


Figure 11. Effeciency of lime and cement upon swelling potential reduction for weathered marls

3.6.2 Strength

Values of the unconfined compressive strength versus the amount of lime or cement added are given in Figure 12(a). Comparing the results, it can be obvious from the graphs that the weathered marls show greater resistance when treated with lime than when treated with cement. This confirms once again the aptitude of lime to react better with such soils than cement.

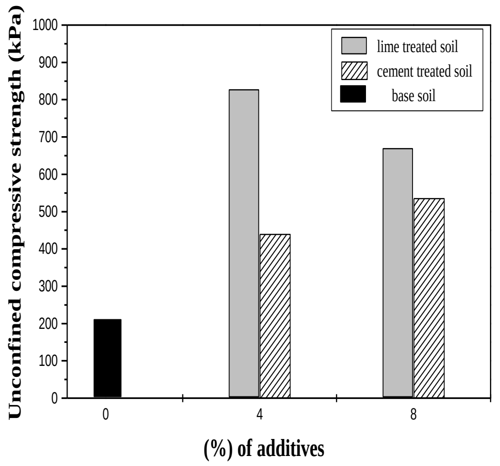


Figure 12 a. Effeciency of lime and cement upon strength increase for weathered marls

This fact is again well illustrated when plotting (CBR) values versus the % of additives added to the soil, where the greatest values are obtained with lime treated soil, Figure 12(b).

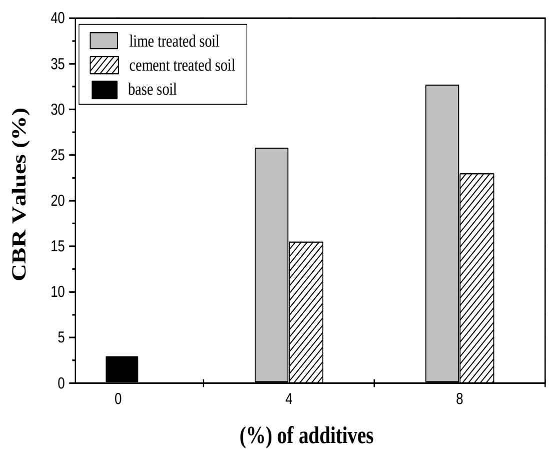


Figure 12 b. Effeciency of lime and cement upon bearing increase for weathered marls

4 CONCLUSIONS

Marls are clayey fine soils with a certain amount of calcium carbonate. They are known for their evolvable character resulting from physical and chemical reaction. Nevertheless, previous studies within the literature have shown the positive effect of mainly lime and with lesser degree cement in treating clayey soil by controlling their workability, volume changes (compressibility and swelling) and by improving their strength (bearing capacity).

Based upon the results obtained from this study, it can be concluded that:

- Both lime and cement can be used to stabilise the weathered marls.
- Volume changes (shrinkage and swelling) and plasticity are both reduced with addition of a small amount of lime or cement.
- There is an increase in strength (CBR and UCS values) with addition of a small amount of either lime or cement.
- The strength increases linearly with cement contents. However, there is an optimum value for lime where above it, there in no gain in strength.
- The optimal lime value for the weathered marl used in this study is about 4%.
- Lime is more efficient in treating weathered marl than cement.
- Weathered marls of the area of Algiers can be efficiently stabilised by addition of lime in a proportion of 4% to 8% by weight maximum.

References

Bergado, D.T., Anderson, L.R., Miura, N. and Balasas Ramarriam, A.S. 1996. Soft ground improvement in low land and other environment. *American Society of Civil Engineers Press*.

Bell. F.G. 1996. Lime stabilisation of clay mineral and soils. *Engineering Geology*, **42**, pp. 223-237

Bell, F.G. 1994. An assessment of Cement-PFA and Lime-PFA used in stabilisation. *Bulletin of the International Association of Engineering Geology*. No. 49, Paris, pp. 25-32.

Bell, F.G. 1993. Engineering treatement of soils. E & FN SPON London.

Bell, F.G. 1988 a. Stabilisation and treatment of clay soil with lime, Part 1. *Ground Engineering, pp. 10-15.*

Bell, F.G. 1988 b. Stabilisation and treatment of clay soil with lime, Part 2. *Ground Engineering, pp. 22-30.*

Bell, F.G. 1976. The influence of the mineral content of clays and their stabilisation with cement. *Bulletin Association Engineering Geologist*, Vol. **13**, pp. 267-278.

Imelhaine, A. 2009. Comportement des Marnes au Traitement à la Chaux et au Ciment. *MSc thesis, Civil Engineering Department, Blida University.*

Mitchell, J.K. 1976. The properties of cement–stabilised soils. Residential Workshop on Materials and Methods for Low Cost Road, Rail and Reclamation Works. Leura, Australia, pp. 365-401.

Rogers, C.D.F., Glendinning, S.1996. Modification of clay soils using lime. In Rogers, C.D.F., Glendinning, S. and Dixon, N. (eds.), Lime stabilisation. Thomas Telford, London, pp. 99-114.

Rogers, C.D.F. and Glendinning, S. 1997. Improvement of clay soil in situ using lime piles in the UK. *Engineering Geology* **47**, pp. 243-257.