Improvement of the Engineering Behavior of Plastic Soils Using Lime and Hydraulic Binders

Hassiba Kherrouba, Riad Benzaid, Chahra Yellas and Mustapha Tekkouk

Abstract

Once wet or saturated, clays become soft and have low compressive strengths, which in the presence of loads lead to excessive settlements. This reduction in compressive strength often causes damage to infrastructure. To remedy this problem, soils can be stabilized by adding cement or lime. Such stabilization methods improve the various technical properties of the stabilized soil and generate an improved material. The present work consists of a laboratory study carried out on two types of plastic soils (clay and marl) stabilized according to various doses of lime, cement, and with a mixed lime–cement treatment. The obtained results show that the impact of the lime treatment makes the mixture less sensitive to water, hence flattening the Proctor curve and increasing the optimum water content. Unlike the use of cement where mixed treatment (lime–cement) or the water content of the soil–cement or soil–lime–cement mixture is reduced, on the other hand, there are no significant changes to the Proctor curve.

Keywords

Hydraulic binders · Clays · Marls · Atterberg limits · Compaction characteristics

H. Kherrouba · R. Benzaid (✉) · C. Yellas · M. Tekkouk
Geological Engineering Laboratory (LGG), Jijel University, Jijel, Algeria
e-mail: r_benzaid@univ-jijel.dz

1 Introduction

The concept of stabilization is very old. At the time of the Pharaohs, the Egyptians built roads with stabilized earth, while the Greeks and Romans used lime as a stabilizer in construction projects (McDowell, 1959). In 1915, cement was introduced as a stabilizer to build a street in Sarasota, Florida, and in 1924, lime was used in road embankments to improve load-bearing capacity and respond to the growth in vehicle traffic (Firoozi et al., 2014; Wang, 2002). Nowadays, the stabilization of soils by adding cement or lime is a widely used technique in the world, especially in road projects in order to improve the geotechnical properties of soils (Bouras et al., 2020; Firoozi et al., 2017; Harichane et al., 2012; Mahamedi & Khemissa, 2015; Pourakbar & Huat, 2017). The aim of the experimental work presented in this paper is to evaluate the efficiency of lime and cement additions on the Atterberg limits and the compaction curves of plastic soils.

2 Methods and Materials

Physical characteristics and Atterberg limit test results of both soils used in this study are presented in Tables 1 and 2, respectively.

Based on these results, clay soil is found to be moist dense to moderately dense, while marly soil is slightly moist dense to moderately dense soil.

For clay soil, the plasticity index is equal to 41.14%, which indicates a very plastic soil. Whereas, the consistency index (IC) of 0.87 corresponds to plastic soils. For marly soil, the plasticity index (IP) is equal to 11.97%, which characterizes soil with low plasticity. The consistency index (IC) equal to 0.99 corresponds to plastic soils.

The experimental program carried out in this study is presented in Table 3.

Z. A. Ergüler et al. (eds.), *Selected Studies in Geotechnics, Geo-Informatics and Remote Sensing*, Advances in Science, Technology & Innovation, https://doi.org/10.1007/978-3-031-43759-5_43

Table 1 Physical characteristics of the two soils used in this study

Physical properties	Clay soil	Marly soil
Wet unit weight γ_h (kN/m^3)	21.76	22.20
Dry unit weight γ_d (kN/m^3)	20.00	18.77
Water content w (%)	29.00	19.00

Table 2 Atterberg limit test results

Consistency parameters	Clay soil	Marly soil
Water content w (%)	29.00	19.00
Plastic limit W_P (%)	23.56	18.99
Liquid limit W_L (%)	64.70	30.96
Plasticity index IP	41.14	11.97
Consistency index IC	0.87	0.99

3 Analysis and Discussion of Experimental Results

3.1 Soil Treatment with Addition of Lime

From the obtained results, it can be seen that the addition of lime has a remarkable influence on the Atterberg limits of both studied types of soil. It is clear that an increase in the percentage of lime in the treated soil induces a significant increase in the plastic limit (WP) than for the liquid limit (WL). On the other hand, increasing the percentage of lime in the treated soil considerably reduces the plasticity index (IP). Indeed, with 4% added lime reduced the plasticity index (IP) of clays by 37%, while that of marls was only 22%.

3.2 Soil Treatment with the Addition of Cement

Adding cement to soils gave the same effect as adding lime, with some exceptions for clays. First, treating the marl soil with cement increased both WL and WP with a decrease in the IP. On the other hand, for clay soil, the addition of cement certainly increased the WL and WP. These increases, recorded at rates 2 and 4% of cement, were reduced to 6% of the added product. The 6% represents the saturation value beyond which the cement treatment is no longer effective for clay; we have certainly reached the saturation threshold for clays.

Table 3 Details of the experimental program

Series of tests carried out	Soil type	Atterberg limits' testing	Observations
Series N ° 01: Effect of soil treatment with lime and/or cement on Atterberg limits	Clay soil	Reference soil	Without treatment
		Soil treated with lime	2, 4 and 6%
		Soil treated with cement	2, 4 and 6%
		Soil treated with lime and cement	2, 4 and 6%
	Marly soil	Reference soil	Without treatment
		Soil treated with lime	2, 4 and 6%
		Soil treated with cement	2, 4 and 6%
		Soil treated with lime and cement	2, 4 and 6%
Series N ° 02: Effect of soil treatment with lime and/or cement on compaction characteristics	Clay soil	Reference soil	Without treatment
		Soil treated with lime	2, 4 and 6%
		Soil treated with cement	2, 4 and 6%
		Soil treated with lime and cement	2, 4 and 6%
	Marly soil	Reference soil	Without treatment
		Soil treated with lime	2, 4 and 6%
		Soil treated with cement	2, 4 and 6%
		Soil treated with lime and cement	2, 4 and 6%

3.3 Mixed Treatment with the Addition of Lime and Cement

The mixed treatment of the studied soils (clay and marl) with lime and cement significantly reduced the WL of both soils. On the other hand, for the WP, after an increase with the percentages of the mixed treatment of 2 and 4%, a decrease was recorded at the threshold of 6% for both soils studied. What confirms once again that this value of 6% is a saturation value beyond which the treatment is no longer effective is the saturation threshold. The IP decreased in both cases.

3.4 Effect of Treatment with Lime and/or Cement on Proctor Curves

The sensitivity to water of the tested samples was reflected in the various shapes of the Proctor curves (according to Figs. 1 and 2). We noted that for the natural state of clay and marl soil, the compaction curve has an accentuated shape, which explains the great sensitivity of fine soils to water. After treatment with lime with additions of 2, 4, and 6%, the Proctor curves of the clays shifted to the right; they have a flattened shape which reflects the low sensitivity of these mixtures to water (Fig. 1). In Fig. 2, the lime treatment of marls with additions of 2, 4, and 6% decreases the density of the optimum Proctor than that of clays, but without a considerable increase in optimal water content.

The treatment of soils with cement improves the initial characteristics of the plastic soil. It is mainly used for obtaining rapid development of mechanical resistance. The water content of the mixture decreased due to the addition of dry materials, the consumption of the necessary water for the hydraulic setting of the cement, and the evaporation of water by aeration of the soil during mixing. On the other hand, no significant modification observed on Proctor curve apart from a moderate flattening which induces a reduction in the water sensitivity of the treated soil (Figs. 3 and 4).

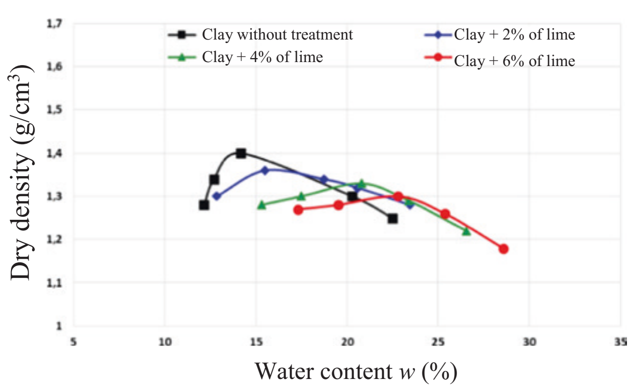

Fig. 1 Lime treatment of clay soil

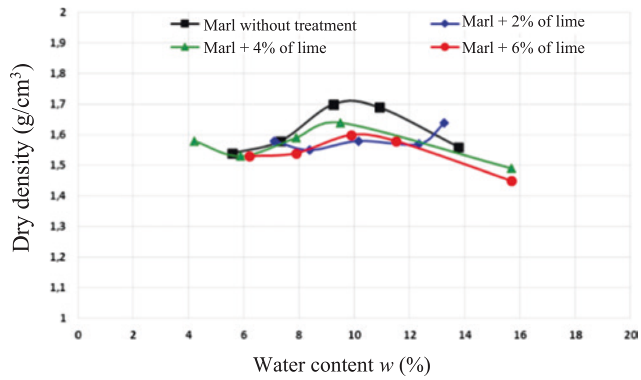

Fig. 2 Lime treatment of marly soil

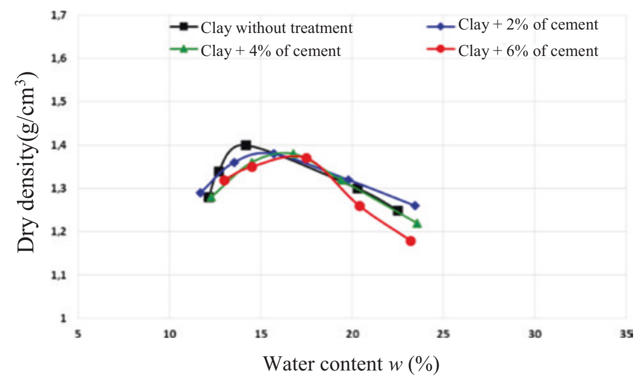

Fig. 3 Cement treatment of clay soil

The mixed treatment using lime and then cement is applied to poorly plastic soils, generally intended for subgrade or pavement layer. The action of the lime helps to bring the soil to an optimal state for treatment with cement. The more or less flattened Proctor curves in Figs. 5 and 6 reveal that the mixed treatment makes the soil less sensitive to water with an optimal reduction in water content compared to previous treatments.

4 Conclusions

The decrease in the water content of a lime treated soil is of 1–2% for 1% addition of lime. Adding lime in clay soil develops an agglomeration of fine clay particles into coarser and more friable elements, and this is flocculation. The impacts of these reactions on the soil–lime mixture are a decrease in the IP, a flattening of the Proctor curve with a decrease in density, and an increase in the optimum water content.

The reactions of cement with a soil essentially consist of hydration of anhydrous calcium silicates and aluminates,

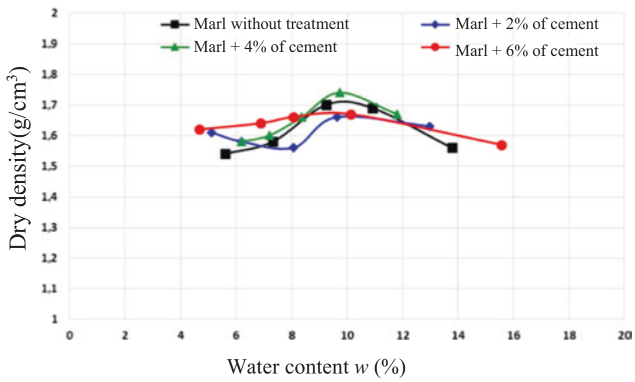

Fig. 4 Cement treatment of marly soil

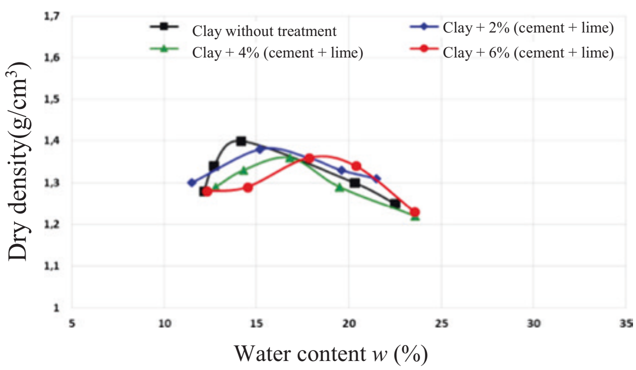

Fig. 5 Mixed treatment (cement and lime) of clay soil

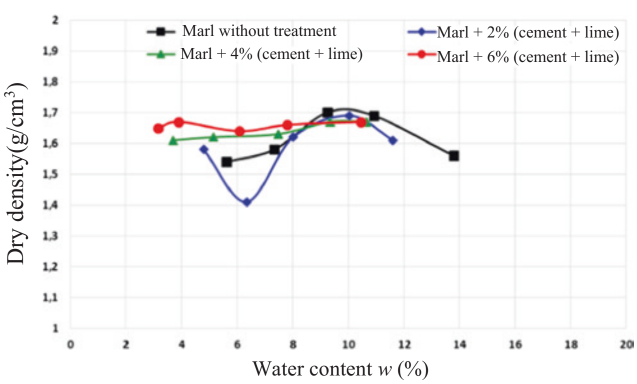

Fig. 6 Mixed treatment (cement and lime) of marly soil

with passage through the solute phase followed by crystallization of the hydrated products, and this is the hydraulic socket. The growth of the formed microcrystals, their entanglement, their progressive felting, coat, and connection of the material's grains to each other form more and more numerous and solid bridges. This quickly leads to the hardening of the mixture, obtaining high mechanical characteristics and its stability to water and frost. The water content of a soil–cement mixture is lowered due to the addition of dry materials; the consumption of water necessary for the hydraulic setting of the cement; evaporation of water by aeration of the soil during mixing. On the other hand, no significant modifications on Proctor curve.

Finally, the mixed treatment (lime and cement) is applied to slightly-to-moderately plastic soils used in sub-layers and, if necessary, in pavement layers. The action of the lime helps to bring the soil to an optimal state for treatment with cement. Thus, a moist clay soil passes almost instantaneously from a plastic state to a solid, friable, non-sticky state and partially loses its sensitivity to water. Its handling on site becomes easy, and its handling behavior and its bearing capacity are improved. The homogeneity that it acquires places it under ideal conditions to undergo the cement treatment.

References

Bouras, F., Tapsoba, N., Martin, M., Sabio, S., Jacquet, A., Beck, K., Belayachi, N., Bouasker, M., Al-Mukhtar., M. (2020). Effect of hydrated lime and cement on the engineering behavior of highly expansive clay. *Athens Journal of Technology and Engineering, 7*(1), 1–14.

Firoozi, A. A., Taha, M. R., Firoozi, A. A., Khan, T. A. (2014). Assessment of nano-zeolite on soil properties. *Australian Journal of Basic and Applied Sciences, 8*(19), 292–295.

Firoozi, A. A., GuneyOlgun, C., Firoozi, A. A. Baghini, M. S. (2017). Fundamentals of soil stabilization. *Geo-Engineering, 8*(26), 1–16.

Harichane, K., Ghrici, M., & Kenai, S. (2012). Effect of the combination of lime and natural pozzolana on the compaction and strength of soft clayey soils: A preliminary study. *Environmental Earth Science, 66*, 2197–2205.

Mahamedi, A., & Khemissa, M. (2015). Stabilization of an expansive overconsolidated clay using hydraulic binders. *HBRC Journal, 11*(1), 82–90.

McDowell, C. (1959) .Stabilization of soils with lime, lime-flyash, and other lime reactive materials. *Highway Research Board Bulletin, 23*, 60–66.

Pourakbar, S., & Huat, B. K. (2017). A review of alternatives traditional cementitious binders for engineering improvement of soils. *International Journal of Geotechnical Engineering, 11*(2), 206–216.

Wang, L. (2002). *Cementitious stabilization of soils in the presence of sulfate* [Doctoral dissertation, Louisiana State University and Agricultural and Mechanical College].