THE EFFECT OF LIME AS A STABILIZING AGENT IN PLASTIC CLAYEY SOILS IN VILA HILL, DURRES, ALBANIA

MUÇI Redi, FOCIRO Oltion, SKRAME Klodian

Abstract. Soil stabilization through the addition of chemical agents such as lime, Portland cement, kiln dust, fly-ash etc., is dependent on the reaction of various oxides such Al_2O_3, SiO_2, with CaO, in the presence of water, to form chemical compounds such as 3CaO-2SiO_2-4H_2O (CSH), as well as CAH, CS'H and CAFS'H. These reactions increase the overall strength parameters of the soil. The purpose of this paper is to analyse the effect of lime in stabilizing clayey soils by influencing the plastic behaviour and thus reducing its swell potential, as well as altering its compaction characteristics. The samples were collected along the steep hill of Kodër Vilë in Durrës, Albania, a coastal area known for its problematic and recurring slope failures. Soil properties were determined along with Atterberg limits, maximum dry density and optimum moisture content. An X-ray diffraction (XRD) analysis was performed on the clay samples in order to determine the mineralogical composition of the soil, as well as an X-fluorescence (XRF) analysis on the soil and the lime for the purpose of identifying the main oxides present in them. The optimum lime content was determined to be 1.75% according to the pH-test. The mixing of this amount of lime with clay resulted in a flattened compaction curve where maximum dry density was reduced from 1.79 g/cm^3 to 1.69 g/cm^3, whereas optimum moisture content increased from 17.1% to 20%. The overall Plasticity Index of the soil decreased from 31.7 to 25.9 after 28 days of curing.

Keywords: soil-mixing, lime, expansive soil, slope stability.

Rezumat. Efectul varului ca agent de stabilizare în pământurile plastice din Vila Hill, Durres, Albania. Adaosul de agenți chimici în soluri, cum ar fi varul hidratat, cimentul Portland, praful de cuptor, cenușă etc., în scopul stabilizării, se bazează pe reacția diferiților oxizi prezenți în aceşti agenți, cum ar fi Al2O3, Si02 şi CaO, în prezența apei, pentru a forma compuși chimici cum ar fi 3CaO-2Si02-4H20 (CSH), precum și CAH, CS'H și CAFS'H. Aceste produse măresc parametrii de rezistență ai solului. Scopul acestei lucrări este de a analiza efectul varului hidratat în stabilizarea solurilor argiloase prin influențarea comportamentului plastic și reducând astfel potențialul de umflare, precum și modificarea caracteristicilor de compactare. Mostrele au fost colectate de-a lungul dealului abrupt al Kodër Vilë din Durrös, Albania, o zonă de coastă cunoscută pentru rupturile sale problematice și recurente. Proprietățile solului au fost determinate împreună cu limitele Atterberg, densitatea maximă uscată și conținutul optim de umiditate. A fost efectuată o analiză a difracției cu raze X (XRD) pe probele de argilă pentru a determina compoziția mineralogică a solului, precum și o analiză X-fluorescentă (XRF) asupra solului și a varului hidratat în scopul identificării principalilor oxizi prezenți în ele. Conținutul optim de var a fost determinat la 1,75% în funcție de testul de pH. Amestecarea acestei cantități de var de hidrat cu argilă a condus la o curbă de compactare aplatizată, unde densitatea maximă uscată a fost redusă de la 1,79 g / cm3 la 1,69 g / cm3, în timp ce conținutul optim de umiditate a crescut de la 17,1% la 20%. Indicele general de plasticitate a solului a crescut de la 27,3 la 40,5. Aceste rezultate indică faptul că sunt necesare mai multe teste pentru a determina cantitatea potrivită de var hidratat pentru reducerea PI.

Cuvinte cheie: amestecarea solului, var, sol expansiv, stabilitate în pantă.

INTRODUCTION

The city of Durrës is located at the Western part of the Albanian lowlands, along the coastline of the Adriatic Sea (Fig. 1). The area under consideration, Kodër Vilë (or Currila), is a hilly section stretching along the coast as a segment of Durrës Mountain. It is composed of soft clays of Pliocene marine deposits, aligned at 45 degrees slope-angle and lacking any significant presence of vegetation. Heavy rainfall during the winter season – reaching a maximum precipitation of 120mm in December (PUMO E. et al., 1990) – and surface-water streams have caused slope failures along the years due to saturation of the clayey soil and loss of strength parameters. The recurrent slope failures have caused considerable damage to the university building and local business located in the area. Furthermore, erosion is a visible phenomenon in this area. Various attempts have been made by the central and local governments for rehabilitating the area, with a major project undertaken by the Ministry of Environment. Two years later, however, the project appears to have failed its objective in stabilising the hill and providing safety for buildings in the area. This paper aims at introducing soil mixing with lime as a possible solution for enhancing the

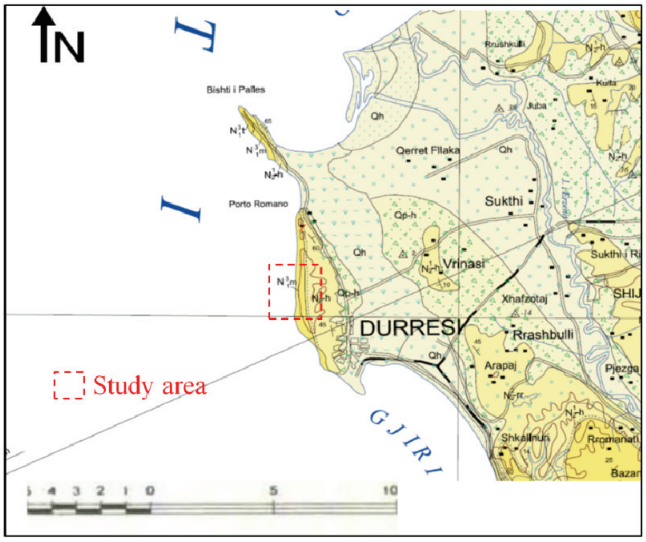

Figure 1. Location of the study area in geological map 1: 200.000 SHALLO et al., 2002.

strength parameters of the soil. The addition of lime for stabilization purposes has recently found a widespread application in various construction projects in Sweden as well as around the world (ÅHNBERG, 2006). Furthermore, lime has been used in soil mixing for the purpose of controlling the volume changes in expansive soils (ZHANG & CAO 2002). The clayey soil from the area was mixed with lime in order to observe the changes in plasticity and compaction characteristics. This data will be used in the future for an evaluation of slope stability.

MATERIALS AND METHODS

The collected samples represent the debris flow material that was deposited near the surface due to slope failure. Initially, the physical properties of the soil, including bulk density, moisture content and specific gravity were determined based on ASTM standards. The soil classification was based on grain size analysis and plasticity of the clay. An X-ray diffraction analysis was conducted in order to identify the main mineralogical components in the clay. Moreover, the chemical composition of the clayey soil and lime were determined using the X-fluorescence by fusion bead method.

Several authors have suggested various amounts of lime to be used in soil mixing as appropriate. For the majority of soil types, 5-10% of lime is suggested (DAS 1990). OLA (1978) proposes 10% of lime for expansive soils, whereas AKAWWI & AL-KHARABSHEH (2002) 3.5-5%. In order to determine the optimal percentage of lime for stabilization, the pH method was used according to ASTM D6276-99. This procedure, based on EADES & GRIM (1966), determines the optimum content of lime by looking at the level of pH that would create the appropriate environment for the pozzolanic reactions to take place. During the reaction of quicklime with water for obtaining hydrated lime, the pH value increases, thus stimulating cation exchange and as well as pozzolanic reactions. The former process, in which calcium and magnesium ions are exchanged for potassium and sodium ions, significantly reduces the plasticity index (ZHANG, 2002). This is followed by flocculation which allows the water to flow through the particles instead of being trapped in them. Furthermore, the increase in pH value causes the dissolution of silica and alumina present in the soil, which initiates the pozzolanic reactions responsible for the long-term strength-gain of the soil.

The pH method examines the bare minimum amount of lime that would potentially be required to mix with the soil for improving its properties, and more specifically reduce the plasticity index. The procedure consists of eleven 150 ml plastic bottles filled with different percentages of lime-soil mixture in water, where pH level is measured for the smallest amount of lime necessary to reach a value of 12.4.

The proportions of lime and soil content in the lime-soil mixture were defined as the ratio of their dry weights to the total mixture. Four curing periods were considered for the mixture: 48 hours, 7 days, 14 days, 28 days. The cation exchange process takes place relatively rapidly, whereas flocculation and the pozzolanic reactions are considered as secondary processes due to the fact that they continue even after a few years (HOPKINS, 2008). The properties of the mixture, such as liquid limit, plastic limit, plasticity index and compaction characteristics, were later considered.

For the purpose of determining the Liquid Limit of the soil, two methods were used, according to ASTM D4318 and BS EN ISO 17892-6:2017, and the results were compared. The first method consists of the Casagrande apparatus, where the liquid limit corresponds to that moisture content for which the groove in the soil inside the brass plate closes for 13mm after 25 blows. The second method used, known as the fall cone test, determines the liquid limit to be the value of the moisture content for which the standard cone will penetrate by 20mm the soil in the cup for five seconds. The two apparatuses are shown in Fig. 2. The plastic limit was determined based on the ASTM procedure.

Furthermore, the Proctor compaction test was performed based on ASTM D558, in order to determine the maximum dry density and optimal moisture content. According to MALLELA et al. (2004), the treatment of soil with lime causes an increase of the optimal moisture content value and decrease of the maximum dry density. The latter is a result of the flocculation process during which the particles occupy a wider space than previously, thus decreasing the density of the mixture, whereas the former stems from the fact that the addition of quicklime increases the percentage of the fine particles present in the soil, thus requiring a larger quantity of water for lubrication during the compaction process. The Atterberg limits as well as compaction properties were compared before and after the treatment of the soil with lime.

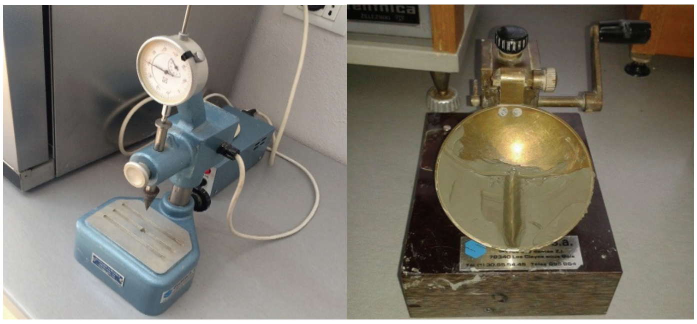

Figure 2. Casagrande and Fall-cone test apparatuses (original).

RESULTS

Soil properties

The Pliocene marine deposits composing the hill at Kodër Vilë in Durrës, have a grey-bluish colour and sparse organic content. The main physical properties are given in Table 1. More than 95% of the material is fine-grained and it has a natural moisture content of 20%. Based on a grain size analysis and the plastic properties, the soil was categorized according to the Unified Soil Classification System (USCS) as Fat Clay (CH), as shown in Fig. 3. This is clay of high plasticity that is associated with a high swell potential.

Table 1. Soil properties.

% passing 75 micron sieve	> 95
% clay	35
USCS classification	CH
Liquid Limit (%)	56.7
Plastic Limit (%)	25.0
Plasticity Index (%)	31.7
Bulk density (g/cm^3)	1.97
Moisture content (%)	20
Specific gravity	2.74

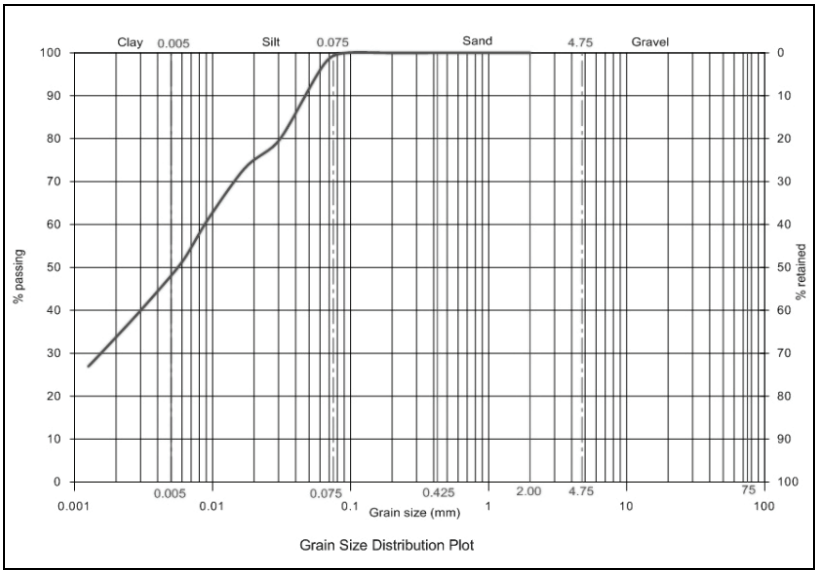

Figure 3. Particle size distribution.

X-ray diffraction analysis

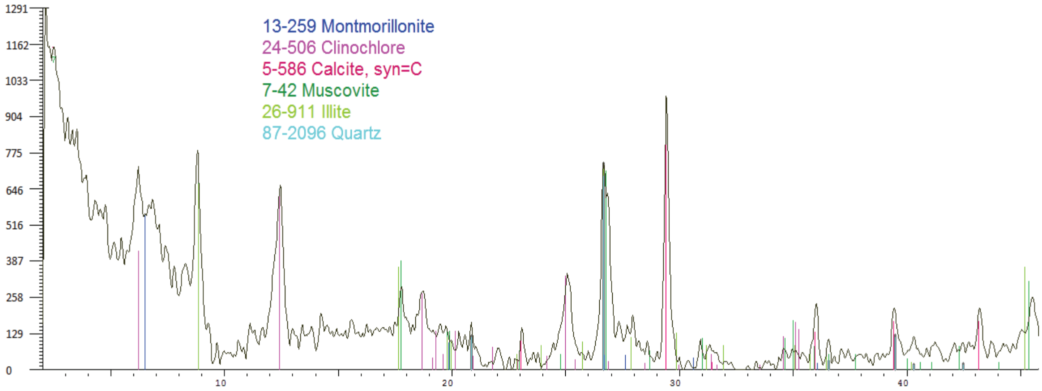

Figure 4. XRD results for the soil.

The x-ray diffraction analysis, as shown in Fig. 4, demonstrates an abundance of quartz and calcite present in the clay. In terms of clay minerals, the presence of illite (or mallachite) and chlinoclore seems significantly larger than that of montmorillonite, which is considered to be a mineral with high swelling potential (CERATO, 2001).

Composition of clay and quicklime

The chemical oxides present in the soil and in the quicklime used as stabilising agent were determined via x-fluorescence by fusion bead method. The main oxides are shown in Table 2:

Table 2. Chemical composition of clay and lime.

	Clay soil	Quicklime
CaO	10.56%	74.45%
SiO_2	46.93%	0.73%
Al_2O_3	12.26%	0.34%
Fe_2O_3	7.01%	0.12%
MgO	5.60%	0.67%
SO_3	0.51%	0.12%
K_2O	2.40%	0.04%
Na_2O	1.51%	0.02%
LOI	12.43	22.4

The optimum lime content was determined based on the minimum amount of lime that would yield a 12.4 value of pH for the lime-soil mixture. For this experiment, eleven different percentages of limes were mixed with the soil. Due to the rather high natural pH value of the clay, namely 9.53, the 12.4 value of pH was obtained for 1.75% of lime added in the mixture, as shown in Fig. 5. This percentage of lime was used for treating the soil when performing the compaction test and in determining the Atterberg limits of the soil.

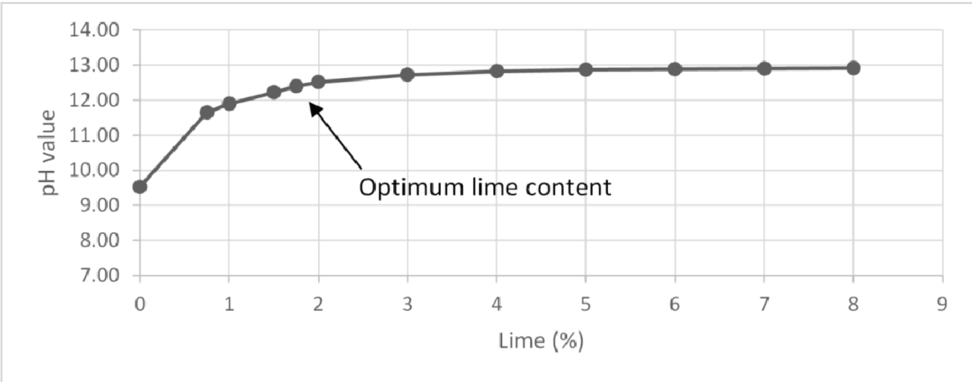

Figure 5. pH test method for determining the optimum lime content.

Compaction test

The results obtained from the Proctor test for compaction are shown in Fig. 6. For the untreated soil sample, the maximum dry density and optimum moisture content were 1.79 g/cm^3 and 17.1%, respectively. The curve is typically bell-shaped. After 1.75% of lime was added to the soil, the compaction curve changed into a flattened-shape one, where the maximum dry density decreased to 1.69 g/cm^3 and the optimum moisture content increased to 20%. The flat shape of the curve indicates that the dry density of the soil varies less with the fluctuation of the moisture content.

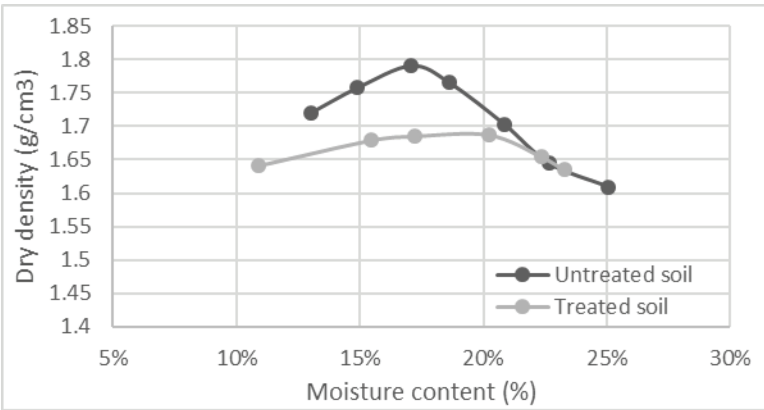

Figure 6. Proctor compaction test for untreated and treated soil.

Atterberg Limits

The Liquid Limit, Plastic Limit and Plasticity Index were determined for both untreated soil and treated soil with 1.75% lime. The determination of liquid limit was conducted with Casagrande method and Fall cone test. It can be observed in Fig. 7 that with the addition of lime the liquid limit decreases and the plastic limit increases, thus decreasing the overall plasticity of the soil. Furthermore, the delay period plays a significant part in continuing this trend, with the final values after 28 days of liquid limit decreasing from 56.7% to 54.2%, the plastic limit increasing from 25% to 28.3% and the plasticity index overall reducing from 31.7% to 25.9% (the results are shown in Table 3). According to MALLELA et al. (2004), a variation of the Plasticity Index from 50% to 40% relates to a decrease in swelling from 45% to less than 20%.

Table 3. Atterberg Limit test results for soil treated with 1.75% lime with Casagrande and Fall-cone methods.

		Casagrande test			Fall-cone test			Average		
Lime %	Delay	LL	PL	PI	LL	PL	PI	LL	PL	PI
0	Natural soil	56.7%	25.0%	31.7%	56.7%	25.0%	31.7%	56.7%	25.0%	31.7%
1.75	2 days	56.4%	26.2%	30.2%	55.3%	27.1%	28.2%	55.8%	26.6%	29.2%
	7 days	55.9%	27.1%	28.8%	55.5%	26.2%	29.3%	55.7%	26.7%	29.0%
	14 days	55.0%	27.5%	27.5%	55.3%	27.6%	27.6%	55.1%	27.6%	27.6%
	28 days	54.2%	28.4%	25.8%	54.2%	28.1%	26.1%	54.2%	28.3%	25.9%

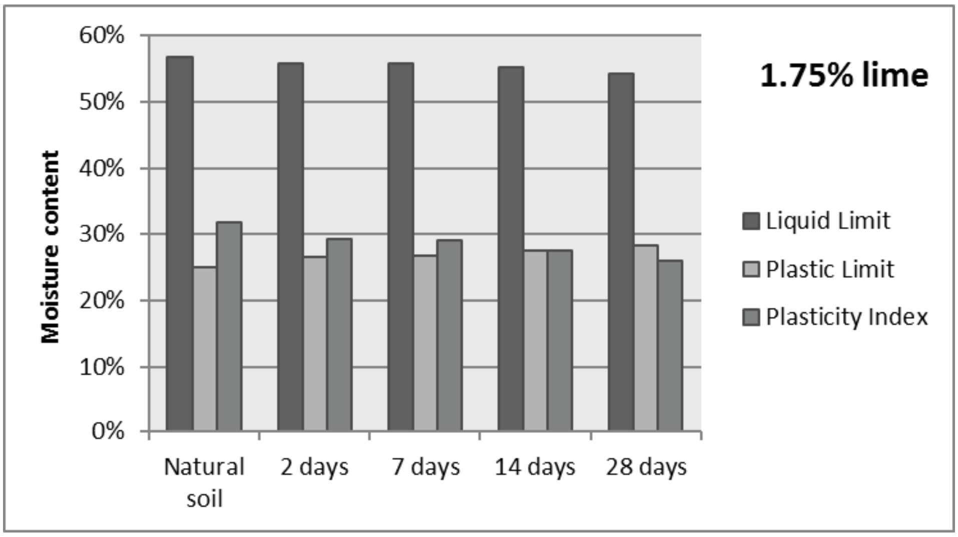

Figure 7. Natural soil vs treated soil with 1.75% lime for 2, 7, 14, and 28 days.

DISCUSSION & CONCLUSIONS

The XRD results showed that montmorillonite was not the predominant clay mineral in the soil. Nonetheless, illite and chlinoclore also have significant expansive potential, based on their specific surface value.

The pH test method determined the optimum value of lime – to be used as a stabilizing agent – to be 1.75%. With the addition of this percentage of lime, the mixture reached the appropriate pH level of 12.4, necessary for the stabilizing chemical reactions to take place.

With the addition of lime, the compaction curve obtained from the Proctor test flattened from a bell-shaped curve and shifted towards the right. A flat curve shows that the dry density (and therefore the volume) does not fluctuate as much with the change in water content.

The value of PI decreased with the addition of 1.75% lime. This effect amplified with the curing time. A higher amount of lime should be used for the value of PI to decrease significantly, since it is considered to be an indicator of swelling potential and thus directly affecting the stability of the slope.

Overall, the addition of 1.75% of lime in the soil, as a minimum amount indicated by the pH method, marginally improved the compaction parameters of the soil and decreased the PI value. Future research will consider the addition of higher percentages of lime in order to assess the increase in strength parameters and soil stability.

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Muci Redi
Faculty of Geology and Mining,
Department of Applied Geology, Environment and Geoinformatics, Tirana, Albania.
redi.muci@fgjm.edu.al

Fociro Oltion
Faculty of Geology and Mining,
Department of Applied Geology, Environment and Geoinformatics, Tirana, Albania.
oltion.fociro@fgjm.edu.al

Skrame Klodian
Faculty of Geology and Mining,
Department of Applied Geology, Environment and Geoinformatics, Tirana, Albania.
klodian.skrame@fgjm.edu.al

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