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# LABORATORY INVESTIGATIONS TO DETERMINE THE EFFECT OF LIME IMPROVEMENT OF SOFT SILTY SOIL

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Lime stabilization as a method for soil improvement is benefitial for number of important engineering properties, such as: strength, resistance to fracture, resilient properties and reduced swelling. This paper briefly describes the application of quicklime to stabilize soft soil. Many laboratory tests have been carried out on silty soil to determine the improvements for lime in varying percentages. The laboratory investigations for different lime contents preparing with optimum moisture content and sample curing under controlled conditions were carried out. The investigation of both treated and untreated soil are focused mainly on the strength parameters, changes in the plastic properties, compaction requirements, California Bearing Ratio and compressibility characteristics of the lime-soil mixtures. Significant improvement and stabilization of the silty soft soil has been observed for 4 percent of lime admixtures.

**Keywords:** Stabilization, soil improvement, quicklime, silty soft soil.

## INTRODUCTION

Soils vary widely in engineering properties and often local soils are not adequate to meet the support requirements of a construction project (Slag Cement Association, 2005). Constructions over soft soil are one of the most frequent problems in many parts of the world (Emilliani and Ismail, 2010). Thus, soil stabilization has become the major issue in geotechnical and structural engineering. The literature review has shown that many researchers analyze the effectiveness of using different materials as soil stabilizers. Several materials can be used as soil stabilizing agents e.g. lime, cement, fly ash and their mixtures.

Soils can be improved by adding lime to the soil, mixing thoroughly with a measured amount of water, and densely compacting the mixture. Lime stabilization is particularly important in road construction for modification of sub-grade soils, sub-base materials and base materials. It may be used for shorter-term soil modification e.g. to provide a working platform at a construction site. Through stabilization, it has been found that not only mechanical properties were improved, compressive strengths and bearing capacity were increased, but also durable pavement was created. Lime improves the strength of soils by three mechanisms: hydration, flocculation and cementation. The first and second mechanisms occur almost immediately upon introducing the lime, while the third is a prolonged effect. The main objective of this paper is to evaluate the effects of the lime on silty soft soil.

## TREATED MATERIALS

Disturbed soil samples were obtained from excavation pit at 2.0m depth. The soil samples were subjected to classification laboratory testing.

A summary of physical properties of the tested soil is presented in table 1. The grain size distribution curve indicated that the soil is composed of 62% silt, 30% fine sand and 8% clay. Based on the Unified Soil Classification System (USCS) the soil is low plasticity clay (CL). The soil also classified as A-6 (9) soil in accordance with the AASHTO classification system.

**Table 1.** Physical properties of untreated soil

| Characteristics | Values, description |
|---|---|
| Colour | dark brown |
| Natural water content [%] | 29.2 |
| Field dry unit weight [kN/m$^3$] | 15.1 |
| Specific gravity | 2.79 |
| Passing No. 200 sieve [%] | 73 |
| Clay content (d<2μm) [%] | 8 |
| Plasticity Index [%] | 12.2 |
| OMC [%] | 15 |
| MDD [kN/m$^3$] | 18.3 |
| CBR [%] | 2.67 |
| Activity | 1.52 |
| USCS | CL |
| AASHTO Class. System (GI) | A-6 (9) |

The form of the lime could be either quicklime (CaO), or hydrated lime (Ca(OH)2). Quicklime hydrates with the soil moisture to become hydrated lime and therefore acts as a better drying agent before providing the calcium to react with the silica and alumina in the soil. Table 2 presents the chemical compositions of quicklime used in this research. The optained LOI is 27.26 %.

**Table 2.** Chemical compositions of quicklime

| compound | quicklime [%] | compound | quicklime [%] |
|---|---|---|---|
| $SiO_2$ | 0.10 | $SO_3$ | 0.11 |
| $Al_2O_3$ | 0.61 | MgO | 0.97 |
| $Fe_2O_3$ | 1.45 | CaO | 69.15 |

## TEST PROCEDURES FOR SOIL – LIME MIXTURES

The laboratory testing procedures include determining optimum lime requirements and moisture content, preparing samples, and curing. Curing is important for chemically stabilized soils because lime-soil reactions are time and temperature dependent.

All laboratory tests were carried out according to Macedonian standards but also some recommendations of ASTM standards had been used.

The tests were carried out on specimens of soil-lime mixtures with different percentages of lime (2, 4, 6, 8, 10 %) added with respect to the dry weight of soil. To determine the optimum lime content, the Eades and Grim pH test was performed. Change of soil plasticity under the effect of lime in various percentages was measured after 1 hour of primary mixing, while changes in the Proctor rates was calculated after a mellowing period of 24 hours. The California bearing ratio (CBR) was performed after a sample curing for 7 days at 40°C and then soaked for 4 days. The specimens for oedometer test cured 7 days at 23°C. The cylindrical samples, of dimensions 50x110 mm, were prepared and compacted with optimum moisture content to obtain the Unconfined Compression Strength (UCS) after curing for 3 days at 50°C, 7 days at 45°C and 28 days at 23°C.

## RESULTS AND DISCUSSIONS

### pH test

The Eades and Grim test is used to approximately determine optimum lime content required to satisfy immediate lime-soil reactions and still provide significant residual calcium and high system pH (about 12.4 at 25°C) (Dallas and Yusuf, 2001). This is necessary to provide proper conditions for long-term pozzolanic reaction that is responsible for strength and stiffness development.

The values in table 3 indicate that there is significant increase in pH when 2% lime is added, but the increase diminishes as lime is further added to the soil.

**Table 3.** Physical properties of lime-soil mixtures

| Lime [%] | 0 | 2 | 4 | 6 | 8 |
|---|---|---|---|---|---|
| pH [/] | 8.21 | 12.26 | 12.35 | 12.41 | 12.42 |
| LL [%] | 29.7 | 29.3 | 30.4 | 29.7 | 30.0 |
| PL [%] | 17.5 | 23.3 | 22.9 | 23.0 | 23.3 |
| PI [%] | 12.2 | 6.0 | 7.5 | 6.7 | 6.7 |

All pH values of the different mixtures are in correspondence with the recommended values.

### Atterberg limits

Liquid limit (LL), plastic limit (PL) and plasticity index (PI) data obtained on the five mixtures are presented in table 3. The LL seems unaffected by the lime content, the PL increases and the PI decreases when 2% lime is added to soil. The further addition of lime does not change the plasticity.

### Compaction

Standard Proctor compaction test was conducted on the five mixtures. The addition of lime to the soil caused reduction in the maximum dry density (MDD) and increase in the optimum moisture content. The typical compaction curves of different soil-lime mixtures are presented in Figure 1.

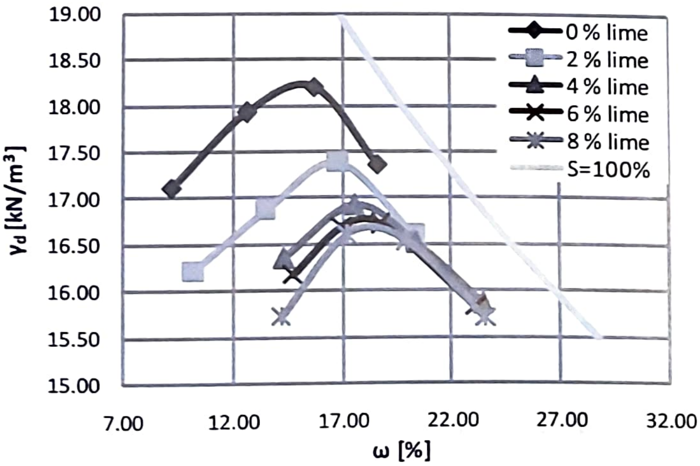
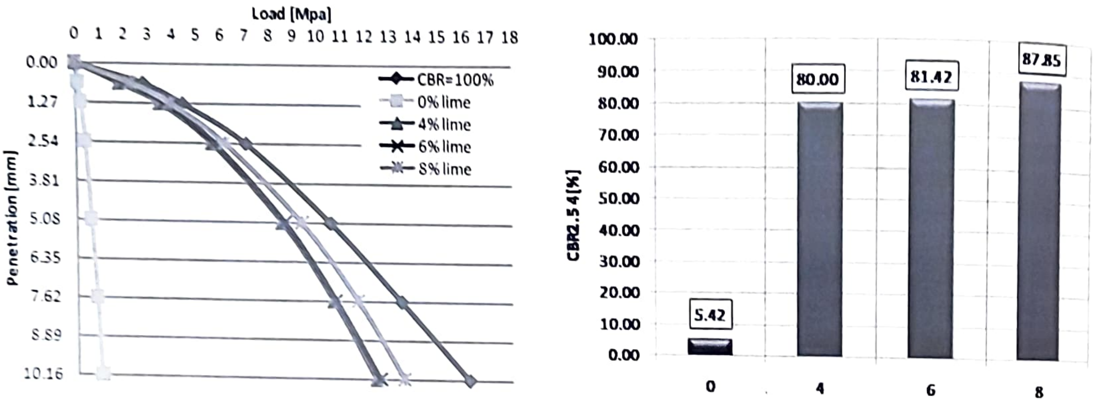



**Figure 1.** Moisture – dry density relationship

Although not investigated, is expected that the time of curing can contribute by increase in the optimum moisture content.

## California Bearing Ratio

The California bearing ratio (CBR) of a compacted soil is determined by comparing the penetration load of the tested soil to that of a standard high quality crushed stone rock. The results are used to evaluate the relative quality and strength of a soil. The results presented in figure 2 and 3, indicate that as lime content is increased there is an increase in the CBR value. If 4 % lime is added to soil and cure 7 days, the CBR increase is significant. Following the recommendation for optimal lime content (AASHTO Classification), the strength and deformability parameters were investigated for 4, 6 and 8 % of lime.




a) b)

**Figure 2.** a) Load versus penetration data obtained from a CBR test and b) CBR values for penetration of 2.54 mm for different lime content

### ometer test

The apparatus used was standard one-dimensional oedometer. Soil-lime mixtures were blended and moistened, and then allowed to sit for 3 hours before compaction to simulate the delay that typically occurs in the field. All remolded specimens were left 7 days to cure before testing. This process allowed the water to be distributed uniformly within the sample without any loss of moisture. Figure 3 shows values of the compressibility modulus Mv (Eoed) obtained on all four mixtures.

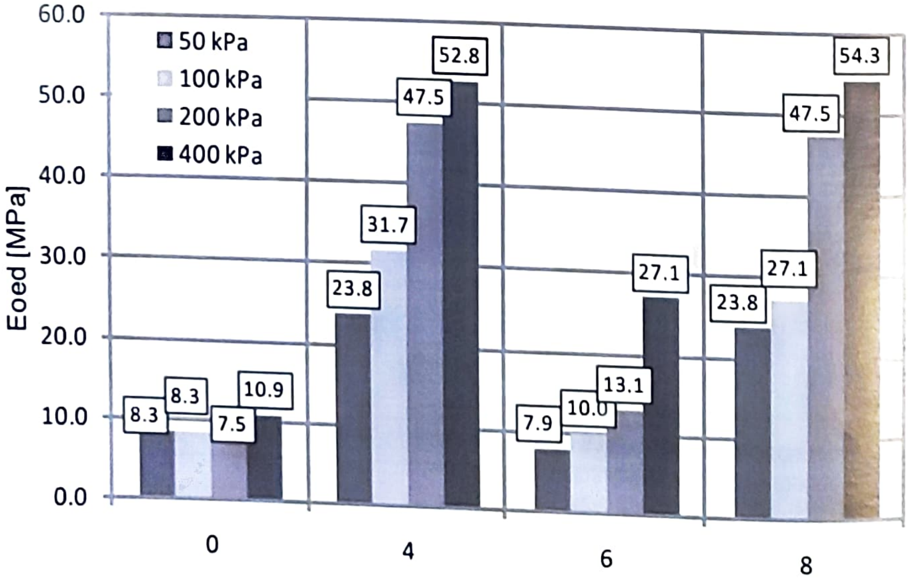



**Figure 3.** Modulus of compressibility versus lime content

There is an increase in Eoed as lime content increases to 4%. Unexpected decrease in Eoed from 4 to 6 % is registered, especially in light of the values obtained for 8 % of lime content.

## Unconfined Compression Strength (UCS)

To evaluate the effect of lime content, UCS samples are prepared for un stabilized and stabilized soil at three lime contents (4, 6 and 8%).

Lime is thoroughly mixed with the dry soil at OMC and placed in plastic zip-lock bags for 1-24 hours. After the mellowing period specimens were compacted in accordance with standard proctor test.

Specimens were divided into three sets, each consist of two with same lime content. Every set of samples was cured as explained before to evaluate the effect of curing time.

Additionally, an identical set of replicate samples is tested with capillary soak to evaluate the effect of moisture conditioning.

### Effect of lime content

The effect of lime content is presented in Figure 4.

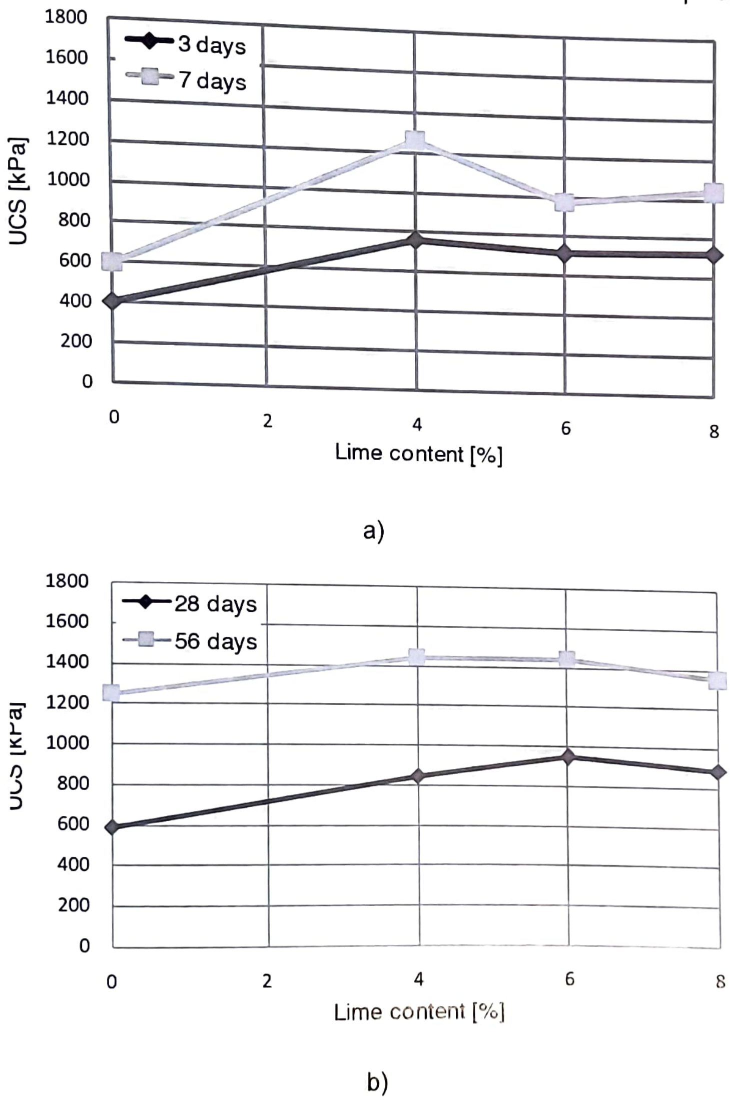


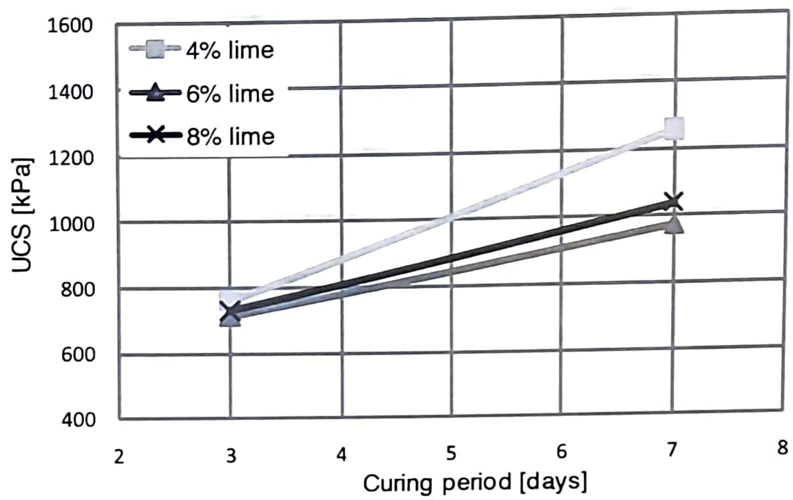

**Figure 4.** UCS versus lime content a) cured at 45°C and b) cured at 23°C

By comparing UCS of soil-lime specimens cured at 45°C, it is seen that unconfined compression strength increases as the lime content increases to 4%. As the lime content increases to 6 or 8%, the UCS decreases. The specimens cured for 7 days with 4% lime content showed the highest values of UCS (1259 kPa). It is clear that only 4% lime is sufficient amount to double the UCS of the soil.

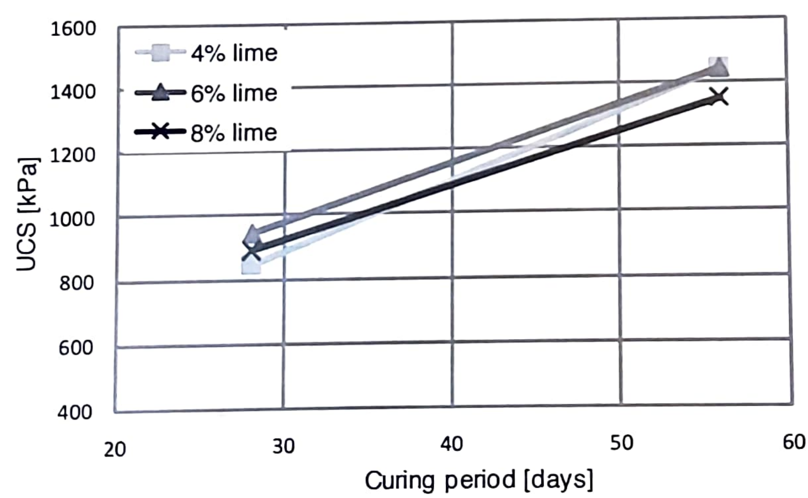
When the specimens cured for 28 an 56 days at 23°C the unconfined compression strength increases as the lime content increases to 6%. As the lime content increases to 8%, the UCS decreases.

## Effect of curing time

The effect of curing time is presented in Figure 5.




a)




b)

**Figure 5.** UCS versus curing time a) 3 and 7 days and b) 28 and 56 days

It is clear that the UCS increases by curing time for same curing conditions. Specimens cured at 45°C for 7 days show 65% higher UCS than the specimens cured for 3 days at the same temperature. Also, the specimens cured at 23°C for 56 days show 71% higher UCS than the specimens cured for 28 days at the same temperature.

## Effect of moisture condition

After curing period, some specimens were exposed to soaking for 24 hours to evaluate the effect of moisture conditioning on UCS. Figure 6 presents the results from UCS performed on the specimens after 7 days at 45°C curing time and 24 hours capillary soaking.

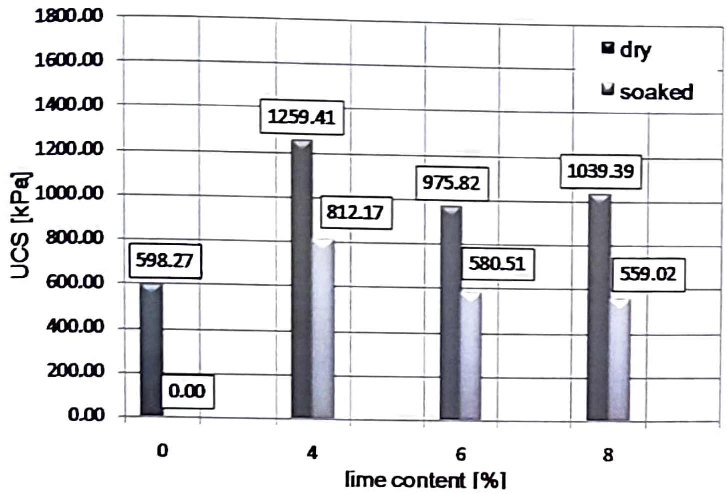



**Figure 6.** Effect of moisture condition on UCS for different lime percentages

It is seen that the unconfined compression strength decreases with increasing moisture after soaking. The untreated soaked specimens don't show any compressive strength.

## CONCLUSIONS

The mixture of lime and silty soil material, has significantly improved the mechanical properties. Even at 2 % of lime, a reduction of moisture content and the plasticity index is around 40% and 45%, respectively. The addition of quicklime increases the optimum moisture while decreasing the maximum dry density due to lower specific weight. Thus, the quicklime can be applied in soils with high moisture content resulting with more efficient compaction.

Addition of lime does have effect on the CBR values. The CBR has improved up to 16 times when 8% of lime is added to soil and cured 7 days and even better results are expected for longer period of time. Lime also can improve the compressibility characteristics of the soil. 4% of lime can increase the compressibility modulus up to six times.

Unconfined compression strength increases depending on the lime content and the duration of the specimen curing, but decreases with increase in the moisture after soaking. The largest increase is observed in specimen with 4% lime where for 7 days of curing at 45°C, the stabilized soil shows 2 times greater strength compared to the unstabilized soil. In this context, the same soil-lime specimens soaked for 24 hours show greater UCS.

A general conclusion would be that the most suitable amount of lime to improve the strength characteristics of this soil would be 4%. On the basis of pH, LL, PL and PI, it can be concluded that 2% lime is optimal.

It would be interesting to investigate the long-term performance of lime stabilized soil.

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