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Importance of Soil Pulverization Level in Lime Stabilized Soil Performance

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Abstract

In this study, effects of soil pulverization level on mechanical properties of a lime stabilized high plasticity clay were investigated. Unconfined compression strength tests were carried on lime stabilized samples which were prepared with two different soil pulverization levels. Fine soil pulverization consisted of 100% finer than No.4 sieve, as typical of laboratory applications. Coarse soil pulverization consisted of 60% of the soil passing No. 4 sieve and all finer than 20 mm, as typical of a high quality field gradation. 4%, 6% and 9% hydrated lime were used by dry weight of the soil for soil stabilization. Unconfined compression tests were carried out after 7, 28 and 56 days of curing. The results revealed that stress-strain behavior differed with soil pulverization levels. Unconfined compression strength and initial modulus values were also significantly affected by soil pulverization levels. Coarse pulverized samples had considerably inferior unconfined compression strength and initial elastic modulus values. This was valid for all curing days. The ratio of values obtained for fine and poor soil pulverization ranged between 1,5 to 2 for unconfined compression strength values and was about 1,5 for initial elastic modulus values. These differences may cause discrepancies between laboratory-estimated and actual field performances of the pavements. It should also be recalled that, in case, field soil gradations are coarser than that of this study, the differences may be larger. Therefore based on the results of this study, it is recommended that laboratory testing for mixture design of lime stabilized soils should be carried out with probable field gradations.

Keywords: P*avement, lime, soil pulverization level, unconfined compression strength, initial elastic modulus*

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1 Introduction

If natural subgrades are not suitable for pavement construction, excavating and replacing the soil with select fill material or increasing the base thickness to decrease the subgrade stresses may be an alternative. In this context, stabilization of clayey soils by lime may be an economical and environmental friendly alternative (Little, 1995, 2000). However, laboratory and field conditions are different by nature and one of the main differences that can occur between laboratory and field is soil pulverization level. Effects of soil pulverization level on mechanical properties of stabilized soils have been studied by some researchers (Grimer and Ross, 1957, Kennedy and Smith, 1986, Petry and Wohlegemuth, 1988, Bozbey and Garaisayev, 2010, Toohey and Mooney, 2011, Beetham et al., 2014) and these studies conclude that designing earthworks based on the parameters determined from laboratory tests could be misleading, because the maximum size of the soil tested in the laboratory is usually less than a few millimeters while clay aggregates in the field may reach the dimension of several centimeters. It is anticipated that if mechanical properties in the field differ from the anticipated values, this may lead to differences in pavement performance.

The experiments presented in this paper were carried out within a joint venture project between Turkish General Directorate of Highways and Istanbul University. The project is titled; "Investigation of the effects of field soil pulverization level on lime stabilized soils used for pavement construction and preparation of a design procedure based on resilient modulus". This project aims to fulfill two important aspects of the subject. The first one is to investigate the effect of soil pulverization level on performance of lime stabilized soils. In this context, unconfined compression strength, CBR, tensile strength and resilient modulus tests were carried out on lime stabilized soils prepared with different lime contents and soils pulverized at different gradation levels. Stress-state dependency of resilient modulus of lime stabilized soils was investigated. Correlations between resilient modulus, elastic modulus and CBR values were searched. Effects of curing, freeze and thaw cycles and wetting and drying cycles on performance of lime stabilized soils were also within the context of the project. Following the laboratory study, multi-layered elastic analyses are being run using the lime stabilized soils' parameters. A design procedure according to mechanistic–empirical pavement design approach will then be prepared related to lime treated subgrades. The results of the study will also be used to prepare a handbook on resilient modulus testing of lime stabilized soils.

The results presented in this study are based on the experiments carried out in this research project. In this context, results of unconfined compression tests carried on lime stabilized soils are summarized. A high plasticity clay was used. The samples were prepared with two different soil pulverization levels which were within the recommended limits in the relevant criteria. 4%, 6% and 9% lime were used by dry weight of the soil and the tests were carried out after 7, 28 and 56 days of curing respectively. Effects of soil pulverization level on unconfined compression strength and initial elastic modulus are evaluated and presented.

2 Literature Review

Lime stabilization is one of the most frequently used soil improvement methods in pavement design. In this context, it is very important that laboratory achieved improvement levels can be obtained in the field. Recent studies have shown that soil pulverization level is a very important parameter in lime stabilization of soils and in case, soil gradations used in laboratory are not met in the field, lime stabilization may not be as effective as targeted. There are some previous studies on effects of soil pulverization level on lime and cement stabilization, which mostly focused on strength and durability. They are summarized below.

The results of Grimer and Ross (1957) showed that coarser pulverization meant lower strength values in cement stabilization. Kennedy and Smith (1986) studied the effect of cement stabilization on unconfined strength values of clayey soils. Pulverization was obtained in two different levels. Pulverized samples were prepared so that 100 percent passed the No. 4 sieve whereas unpulverized samples had 85 percent passing the number 4 sieve and 15 percent having gradation between 38 mm and 20 mm. Cement treated clays had reductions in compression strength values for the unpulverized specimens. The effects of the inclusion of unpulverized clods were more pronounced in high plasticity clays. Even very sandy clays showed significant strength losses when comparing unpulverized to pulverized specimens. Petry and Wohlegemuth (1988) carried out durability tests (wet-dry cycles) in the laboratory using different levels of pulverization ranging from laboratory quality gradations to field gradations. They studied the effects of pulverization on strength and durability of highly plastic clay soils stabilized with lime and Portland cement. Coarse gradation was obtained by achieving a minimum percentage of passing No. 4 sieve as 60 %. For fine gradation, 100% of the soil passed No. 4 sieve. The specimens that were prepared with the finest pulverization had significantly more strength than those prepared with coarser pulverization. Their results revealed that for lime stabilization, coarser gradation required longer curing times than the fine graded materials to reach attainable strength and durability. Based on these results, they recommended that field gradation should be used in laboratory testing, because it represents the field construction conditions better. Bozbey and Garaisayev (2010) studied the effects of soil pulverization on mechanical properties of lime stabilized soils. In their experiments, three different pulverization levels were studied. “Fine pulverization” was defined as 80-90% finer than No. 4, and “coarse pulverization” meant that all the samples passed through 25 mm and only 40% was finer than No. 4. Average pulverization was between these two limits. The results revealed that fine pulverization resulted in much higher unconfined compression strength values than coarse pulverization. Average level of pulverization resulted in moderate values. The results were similar for values of modulus at failure. Another interesting finding was that although modulus values could be approximated from unconfined compression values, they depended strongly on soil pulverization quality. Based on these equations, they concluded that it seemed obligatory to take effect of soil pulverization quality into consideration when using unconfined compression strength values to assign modulus values.

Tang et al. (2011) stabilized soils having four different maximum soil aggregate sizes and they found that the larger the aggregates, the lower was the value of the shear modulus. Modulus and unconfined compression strength testing carried out by Toohey and Mooney (2011) showed that field requirement as 60% of soil conglomerations to be finer than 4.75 mm would yield less homogeneous specimens and greater variability in modulus and unconfined compression strength behavior than was observed in the laboratory (with 100% finer than 4.75 mm). Beetham et al. (2014), emphasized that in site processes, the machinery tended to produce clay clods which may be up to 50 mm in diameter with lime applied to the periphery of these clods. They stresses that in such conditions, lime is initially localized along the periphery of the clods and for the lime-clay reactions to extend beyond the surface of the clods, the calcium ions and hydroxly groups have to transport deep into the clods. This is called diffuse cementation and occurs as a result of lime migration or calcium migration. However, since the clod sizes differ in the field to a great extent (ranging from 5 mm to 20 mm), the rate of change of strength is heterogeneous–that is; fast for the small clods, slow for the larger clods.

Based on these studies, it is clear that soil pulverization level is important for strength and modulus values. It is generally the strength values, which are taken into account in evaluating the level of soil improvement, however, evaluation of modulus values should be equally important, because pavement performance is directly related to the deformation characteristics of the lime stabilized soils. In this context, initial modulus values are also evaluated in this study in addition to strength values.

3 Methodology

The soil used in this study was classified as CH, with a Liquid Limit of 69% and Plastic Limit of 28% according to USCS. The granulometry of the soil showed that 9% of the soil consisted of gravel, 20% was of sand and 71% of fine grained particles. The soil had a soaked CBR value of 3. A locally available hydrated lime was used. Soil was brought from the field in bags and was pulverized to meet two different soil pulverization levels. Fine soil pulverization level was described as pulverization so that 100% passed No. 4 sieve. Coarse soil pulverization level was obtained so that all the soil passed through 20 mm sieve and 60% was finer than No. 4 sieve. Both pulverization levels met the soil pulverization levels in relevant lime stabilization criteria (National Lime Association, 2004, Turkish Lime Stabilization Specification, 2013). Soils were then mixed with 4%, 6% and 9% hydrated lime respectively. Water was added to achieve optimum water contents for each soil and lime composition. One hour mellowing time was allowed before compaction. The mixture was wrapped with nylon sheet to prevent moisture loss during mellowing. Samples were compacted in a specially manufactured compaction mold with application of Standard Proctor Compaction energy level, which is 593.7 kJ/m^3 according to ASTM D698. The samples were 10 cm in diameter and 10 cm in length. Four samples were prepared for each composition. Photos of the soil in its original form and of soil pulverization and compaction processes are given in Figure 1. Laboratory tests were carried out according to relevant ASTM procedures as given in the references. Different curing durations; 7, 28 and 56 days were applied and unconfined compression tests were carried out after the curing period was over. In this study, extended curing up to 56 days was applied in addition to 7 days and 28 days so that effects of extended curing on strength and modulus increase rate for different soil pulverization levels could be observed.

Figure 1. Soil pulverization process and specially manufactured split mold for sample preparation

4 Results

The results of the unconfined compression tests are given in this section. The results are evaluated in terms of stress-strain behavior, unconfined compression strength and initial elastic modulus (modulus corresponding to less than 0,25% vertical strain) values. Average strength and initial modulus values for each composition was evaluated at the end of this section.

Figure 2 presents the results for unstabilized samples, for which only 7 days curing was applied. These results were used as a measure of soil improvement level with lime. Unconfined compression strength values for both pulverization levels were as low as 50-60 kPa with failure strains of about 4%-6%. For unstabilized samples, there was not much difference in stress-strain curves, strength and failure strain values that could be attributed to different soil pulverization levels. The results of unconfined compression strength tests for 4% lime stabilized samples are given in Figure 3. Fine pulverization resulted in considerably higher unconfined compression strength values than its coarse pulverization counterpart. For all curing durations, even after 56 days of extended curing, there were significant differences in unconfined compression strength values for different soil pulverization levels. Due to changes in stress-strain behavior, the initial slopes of the curves obtained with fine soil pulverization were much higher, as an evidence of higher initial modulus values.

The results obtained for 6% lime stabilized samples are given in Figure 4. 6% lime increased the compression strength values considerably. There were significant differences between unconfined compression strength values for fine and poor soil pulverization levels. It was as if the compression strength values were limited to 400-800 kPa even for extended curing conditions. This was contrary for fine soil pulverization, where strength values continued to increase up to 1600 kPa with curing. Initial elastic modulus values were always higher for fine soil pulverization. For this lime content, the difference for different soil pulverization levels was most significant for 56 days cured samples. Figure 5 shows the graphs obtained for 9% lime. Similar evaluations can be made for this lime content. It was interesting to see that even 9% lime could not eliminate the diverse effects of poor pulverization on strength and initial modulus values.

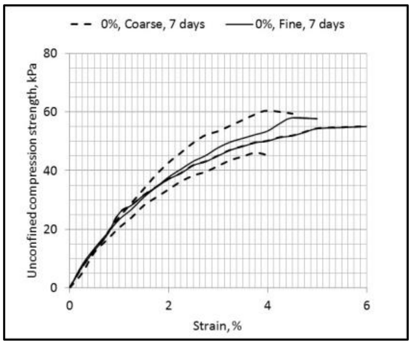

Figure 2. Stress-strain graphs obtained for unstabilized stabilized samples

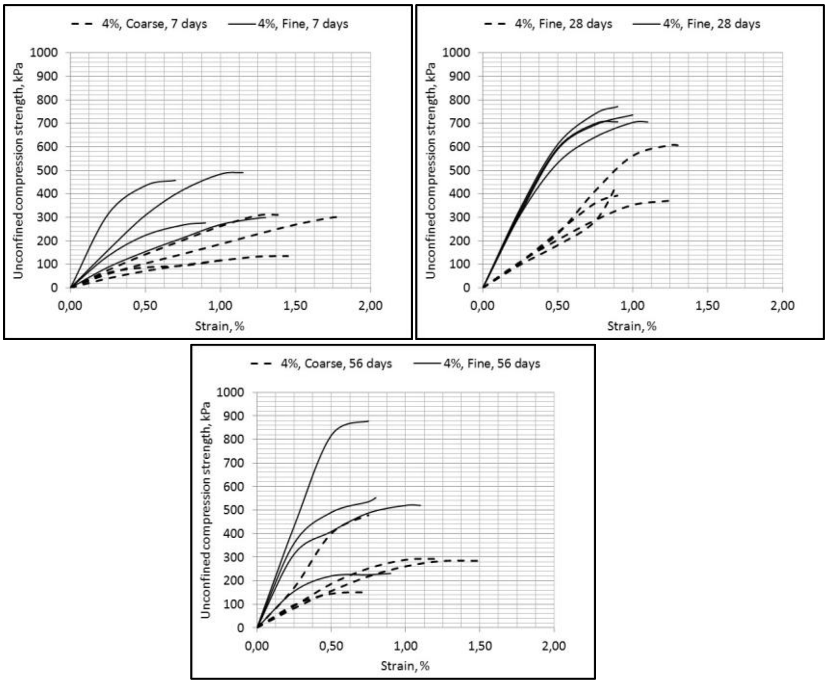

Figure 3. Stress-strain graphs obtained for 4% lime stabilized samples

Figure 6 presents the average unconfined compression strength and initial elastic modulus for each composition. Averaging the values for each composition is logical, because it is strongly possible that, due to the large volumes of soil involved in the field, different depths and parts of a pavement layer (either base, subbase or subgrade) may reach somehow different mechanical properties during their lifetime. Based on Figure 6, average strength and modulus values were good indicators of differences based on soil pulverization levels. As seen in Figure 6, coarse soil pulverization resulted in lower strength and modulus values for all lime and curing day combinations. Neither extended curing up to 56 days, nor use of higher lime contents (up to 9%) could surpass the poor soil pulverization effects.

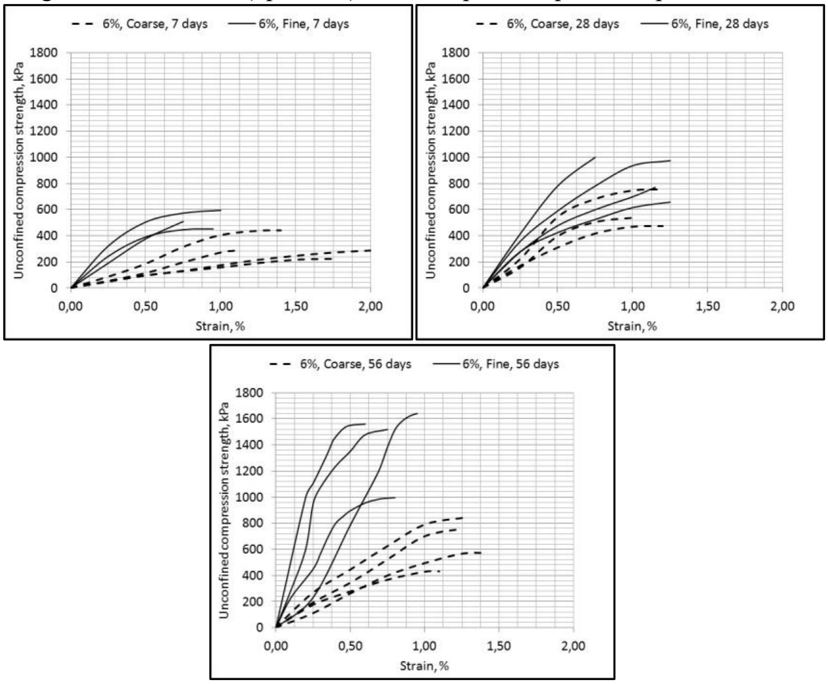

Figure 4. Stress-strain graphs obtained for 6% lime stabilized samples

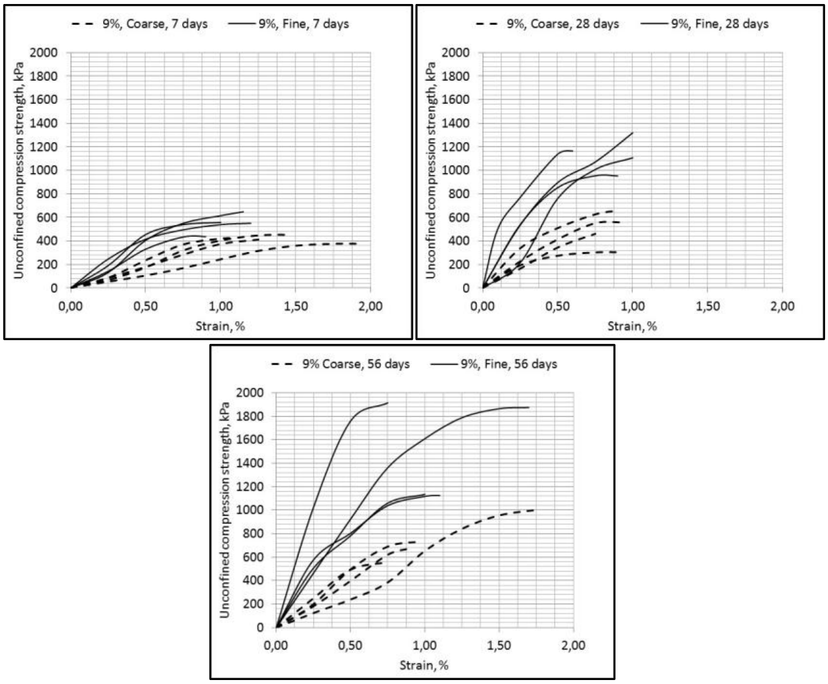

Figure 5. Stress-strain graphs obtained for 9% lime stabilized samples

Figure 7 displays the ratio of unconfined compression strength and initial elastic modulus values obtained for fine soil pulverization and poor soil pulverization as described in this paper. Based on Figure 7, it can be concluded that strength ratio was about 1,5-2 and initial modulus ratio was about 1,5.

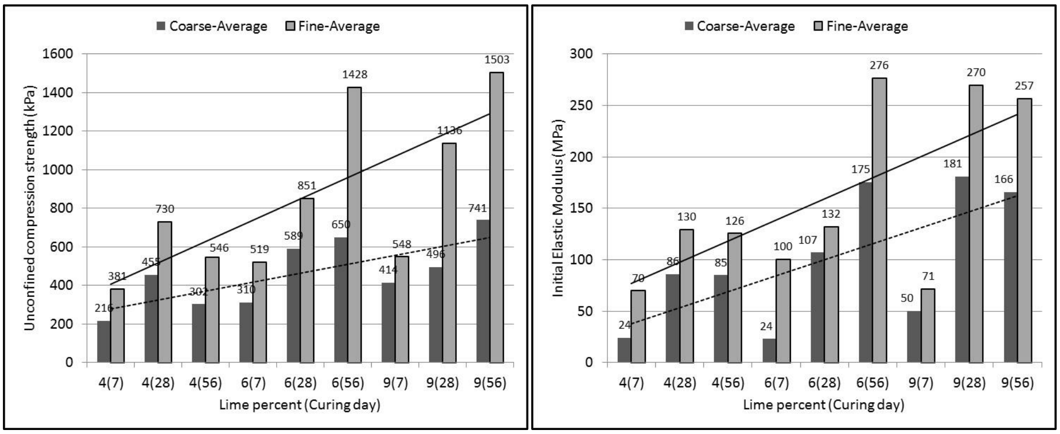

Figure 6. Variation of unconfined compression strength and initial elastic modulus with lime and curing day

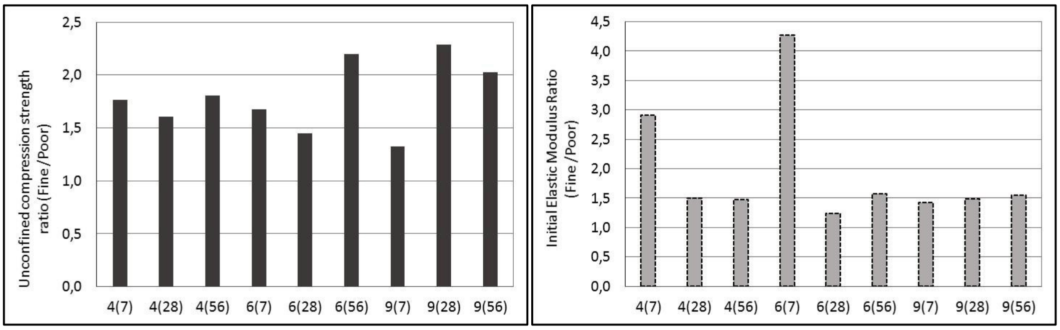

Figure 7. Ratio of unconfined compression strength and initial modulus values for different soil pulverization levels

5 Conclusions

This paper presents the unconfined compression strength test results obtained for a lime stabilized high plasticity clayey soil. The experiments were carried out within the context of a joint venture project carried out between Turkish General Directorate of Highways and Istanbul University, Civil Engineering Department. 4%, 6% and 9% hydrated lime was used. Effects of soil pulverization level on unconfined compression strength and Initial Elastic Modulus values were presented. The results confirm that, soil pulverization level affected these two parameters considerably. Coarse soil pulverization resulted in lower strength and modulus values. The ratio of values obtained for fine and poor soil pulverization ranged between 1,5-2 for strength values and was about 1,5 for initial elastic modulus values. These ratio values can be used to convert laboratory determined values to field values if soil pulverizations are within the limits studied here. If coarser pulverizations are present in the field, the ratios are expected to be higher. The results of this study highlight the importance of using field gradations in laboratory testing protocols for lime stabilized soils, so that field performances will not be lower than that anticipated in the laboratory.

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