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AUTHOR (Capitalize Family Name)	**POSITION**	**ORGANIZATION**	**COUNTRY**
Ilknur Bozbey	Associate Prof. Dr.	Istanbul University, Civil Engineering Department, Avcilar, Istanbul	Turkey
CO-AUTHOR(S) (Capitalize Family Name	**POSITION**	**ORGANIZATION**	**COUNTRY**
Aykan Mert Ahmet Sağlık, Şenol Comez, Birol Demir	Department of Research and Development	Republic of Turkey, General Directorate of Highways, Ankara	Turkey
E-MAIL (for correspondence)	ibozbey@istanbul.edu.tr, aykanmert@yahoo.com		

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ABSTRACT:

Lime stabilized soils are being used in construction of pavements for years worldwide and the design usually incorporates California Bearing Ratio (CBR) or unconfined compression strength values. However, in recent years, resilient modulus has been an important parameter in mechanistic-empirical pavement design. In this context, resilient modulus tests on lime stabilized high plasticity clay were performed within the context of this study. Tests were carried out in laboratories of Turkish General Directorate of Highways. Unstabilized and 4% lime stabilized samples were tested after seven and twenty-eight days of curing. Since it is possible that different soil pulverization levels can be encountered in the field due to different construction procedures, soil used was pulverized in two different levels; 100% passing No. 4 sieve (fine pulverization) and 60% passing No. 4 sieve (coarse pulverization). The results revealed that resilient modulus of unstabilized and lime stabilized soils were affected by the stress state (confining stress and deviator stress), curing duration and soil pulverization level. Lime addition increased the resilient modulus values. However, the amount of increase depended considerably on soil pulverization level. For lime stabilized samples and coarse pulverization, curing increased the modulus values for high deviator stresses. This was probably due to the fact that longer curing time is probably needed for lime particles to reach clay particles in case of coarse soil pulverization. Therefore design of pavements should take into account these parameters, otherwise, performance of pavements with lime stabilized layers may not reach expected levels. These experiments have been carried out within the context of a joint venture project, which is being carried out between Istanbul University and Turkish General Directorate of Highways. The results bring novel contributions to the construction procedures for lime stabilized clayey soils and emphasizes the importance of achieving fine pulverization as best as possible in the field.

EFFECTS OF LIME ON RESILIENT MODULUS PROPERTIES OF A CLAYEY SOIL

Dr. İlknur BOZBEY[1], Aykan MERT[2] Ahmet SAĞLIK[2], Şenol COMEZ[2], Birol DEMİR[2]

[1]Istanbul University, Civil Engineering Department, Avcilar, Istanbul

2 Republic of Turkey, General Directorate of Highways, Department of Research and Development, Ankara
Email for correspondence, ibozbey@istanbul.edu.tr, aykanmert@yahoo.com

1 INTRODUCTION

Lime stabilization is one of the most frequently used soil improvement methods used in pavement construction. In case, readily available soils are not appropriate to be used in subgrade level, lime stabilization of the soils can be an economic and environmental friendly alternative. It is well known that, lime increases the mechanical properties of soils, however, the key to pozzolanic reactivity and stabilization is a reactive soil, a good mix design protocol, and reliable construction practices (www.lime.org). 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. In case, soil gradations used in laboratory are not met in the field, lime stabilization may not be as effective as targeted. Another important point is that current pavement design protocols are based on mechanistic-empirical approaches where resilient modulus values for pavement materials are needed. Therefore dependency of resilient modulus behavior of lime stabilized soils to different parameters, such as; lime content, soil pulverization level, curing time, and environmental conditions are important issues.

The experiments presented in this paper have been carried out within the context of a joint venture project, which is being carried out between Istanbul University and Turkish General Directorate of Highways. This project aims to fullfill two important aspects. The first is to investigate the effect of lime on resilient modulus properties of high plasticity clays. Dependency of resilient modulus on stress states, different curing durations and soil pulverization levels are investigated in detail. Correlations between resilient modulus, elasticity modulus and CBR values are also seeked. Effects of curing, freeze and thaw and wetting and drying cycles are also included within the context of the project. Microfabric analyses will be carried out. At the last stage of the project, multi-layered elastic analyses will be run using the parameters obtained in the experiments. A design procedure according to mechanistic–empirical pavement design approach will 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. It is believed that outputs obtained in this project will be a tool to increase the use of lime stabilization in pavement construction in Turkey.

In this paper, preliminary results obtained in this project will be presented and discussed. Tests were carried out in laboratories of Turkish General Directorate of Highways. In this context, resilient modulus measurements obtained from unstabilized and 4% lime stabilized soils are presented. Two different soil pulverization levels were used in preparation of the samples. Curing durations were 7 and 28 days respectively.

2 LITERATURE SURVEY

Lime can modify almost all fine-grained soils, but the most dramatic improvement occurs in clay soils of moderate to high plasticity. In the short term, calcium cations supplied by the hydrated lime replace the cations normally present on the surface of the clay mineral, promoted by the high pH environment of the lime-water system. Thus, the clay surface mineralogy is altered, producing the following benefits; plasticity reduction, reduction in moisture-holding capacity, swell reduction, improved mechanical properties. In the long term, soil stabilization occurs through a pozzolanic reaction. This reaction produces stable calcium silicate hydrates and calcium aluminate hydrates as the calcium from the lime reacts with the aluminates and silicates solubilized from the clay. (http://www.lime.org). Due to these pozzolanic reactions, substantial increases in strength and modulus values are achieved.

Soil pulverization level has been found to be an important parameter in stabilization of soils. In laboratory, the gradations used for determining the mixture design are usually fine; in other words, 100% passing No. 4 sieve. For this purpose the soil is pulverized to eliminate all the clods. However, in the field, larger gradations are usually encountered, especially when dealing with high plasticity clays because it is hard to eliminate the clay clods. Felt (1964) studied the effects of soil pulverization level in cement stabilization and their results showed that in case less than 80% passed No. 4 sieve, effectiveness of stabilization decreased. The results of Grimer and Ross (1957) were similar; coarser pulverization meant lower strength values. Bozbey and Garaisayev (2010) studied the effect of soil pulverization on mechanical properties of lime stabilized soils. Three different pulverization levels were studied. Fine pulverization (80-90% finer than No. 4) resulted in much higher strength values than coarse pulverization (100% finer than 25 mm and 40% finer than No. 4). Average level of pulverization resulted in moderate values. The results were silimar for modulus values measured through unconfined compression testing. The results obtained by Tang et al. (2011) and Toohey and Mooney (2011) revealed similar results. Effects of soil pulverization on resilient modulus has not been studied before, however, iIt may be anticipated that, soil pulverization affects the resilient modulus values as well.

Elastic modulus is basic property of any paving or roadbed material. However for those materials, which are subject to significant permanent deformation under load, this property may not reflect the material’s behavior under load. Thus resilient modulus refers to the material’s stress-strain behavior under normal pavement loading conditions. The resilient modulus is the most commonly used parameter in pavement design. The guide for design of pavement structures (AASHTO 1993) and the mechanistic-empirical pavement design guide (NCHRP 2004) have been developed and recommended the use of resilient modulus of subgrade soils in pavements structural design and analysis. Resilient modulus of subgrade soil can be estimated by conducting resilient modulus tests on the representative soil samples. Resilient modulus for granular materials and stabilized materials can be determined according to AASHTO method T-307-99. The load applied during the test protocol mimics the load duration and magnitude applied in the field. This test requires a haversine-shaped loading waveform. The load cycle duration is 1 second that includes a 0,1 second load duration and a 0.9 second rest period. The repeated axial load is applied on top of a cylindrical specimen under confining pressure and the total recoverable axial deformation response of the specimen under confining pressure. Total recoverable deformation response of the specimen is measured and used to calculate the resilient modulus. Resilient modulus is the ratio of deviator stress to total recoverable strain.

3 METHODOLOGY

Within the context of this study, effects of lime stabilization on resilient modulus values were investigated. Since different soil pulverization levels can be encountered in field applications, effects of pulverization level were also investigated. Soil brought from the field was pulverized at two different soil pulverization levels and then stabilized with 4% hydrated lime. Different curing durations; 7 and 28 days were applied. Resilient modulus tests were carried out after curing period was over. It should be recalled that additional lime percents and curing durations are also being tested within the context of the study, however, the experiments are still being carried out.

Physical properties of the soil used are listed in Table 1. The soil had a CBR value of 3 and very high swelling potential. Therefore the soil was not appropriate to be used in the subgrade level. Therefore stabilization with lime can be considered to be an alternative. In the experiments, a locally available hydrated lime was used. A photo of the soil in its original form is shown in Figure 1. Since it is a high plasticity clay, there existed a lot of clods of different diameters. This may reflect a typical gradation in the field, if enough consideration is not given during pulverization process.

Figure 1. Soil brought to the laboratory

Table 1. Index properties of the soil

Measured property	Value
Gravel, %	9
Sand, %	20
Silt and clay, %	71
Liquid Limit, %	69
Plastic Limit, %	28
Plasticity Index	41
Soil Classification, USCS	CH
Soaked CBR, %	3
Swelling in CBR, %	6

The soil was first air dried and then pulverized in two different pulverization levels. In “fine” soil pulverization level, the soil was pulverized so that all the soil passed through No. 4 sieve. In “coarse” pulverization, the soil was pulverized so that only 60%-65% of the soil passed through the No. 4 sieve. In all cases, the biggest clod was 20 mm. Before the resilient modulus samples were prepared, soil was air dried, necessary amount of hydrated lime by dry weight was added. In the last stage, water was added to increase the moisture content to optimum moisture content. The mixture was then wrapped with nylon sheet to prevent moisture loss and mellowed for one hour. The soil was then compacted in a special mold to prepare a resilient modulus sample of 10 cm diameter and 20 cm height. Standard Proctor Compaction was applied. The samples were then cured in a curing room for 7 and 28 days. After curing was over, resilient modulus tests were carried out. The details of testing procedure are given in Ozey and Gungor (2008).

4 RESULTS

In the resilient modulus tests, prior to actual modulus testing, specimens were conditioned to minimize the effects of improper contact between the specimen ends and the sample cap and base plate. After conditioning, soils were tested at three decreasing levels of confinement at five increasing levels of axial stress within each confinement stress level. Two samples were tested for each composition and curing durations.

In this study, tests were carried out at different deviator stresses, ranging from 14 kPa, 28 kPa, 42 kPa, 55 kPa and 69 Pa. Confining pressures used were 14, 28 and 42 kPa respectively. These stress levels are consistent with those confronted at the subgrade. The results of the tests are given in Figure 2 to Figure 5.

4.1. UNSTABILIZED SOIL (0% lime)

The results obtained for unstabilized soil (0% lime) are given in Figures 2 and 3. Resilient modulus values for unstabilized samples are important, because they are compared with those of lime stabilized samples to see the level of increased performance.

Figure 2 shows the results for 7 days curing for fine and coarse pulverization levels. In both pulverization levels, there was not a very strong dependency of resilient modulus values on confining stresses, however, when 42 kPa was applied as the confining stress, the values were slightly higher. Resilient modulus values ranged between 50 to 80 MPa for fine pulverization. However, for coarse pulverization, the values were much lower. The values were about 25 MPa for low deviator stresses and decreased to about 10 MPa for very high deviator stresses. The effect of deviator stresses on resilient modulus values was significant. Increased deviator stresses decreased the values considerably. As a result, the ratio of modulus values for fine to coarse pulverization was about 3 to 5. This is an important finding because it shows that soil pulverization level affected the modulus levels considerably even for unstabilized soils.

The results for 28 days curing are presented in Figure 3. For all samples, there was not significant difference for different confining stresses. However, for 42 kPa, slightly higher values were obtained. For fine pulverization, the values were again between 45-60 MPa for low deviator stresses and decreased to 35-50 for high deviator stresses. For coarse pulverization, the results were much lower as they were for 7 days curing. They ranged from 25 MPa to 10 MPa. For all samples, there was a decrease of values with increasing deviator stresses. Decrease in modulus values with increasing deviator stress for fine pulverization was not as significant as it was for coarse pulverization. Fine pulverization seems to result in a more stable structure, which is harder to soften. Since there was no miosture loss during curing, the values are similar with those for 7 days curing. It is anticipated that there should not be significant differences in resilient modulus of unstabilized samples with different curing conditions. Only for prolonged curing durations, effects of aging can be pronounced.

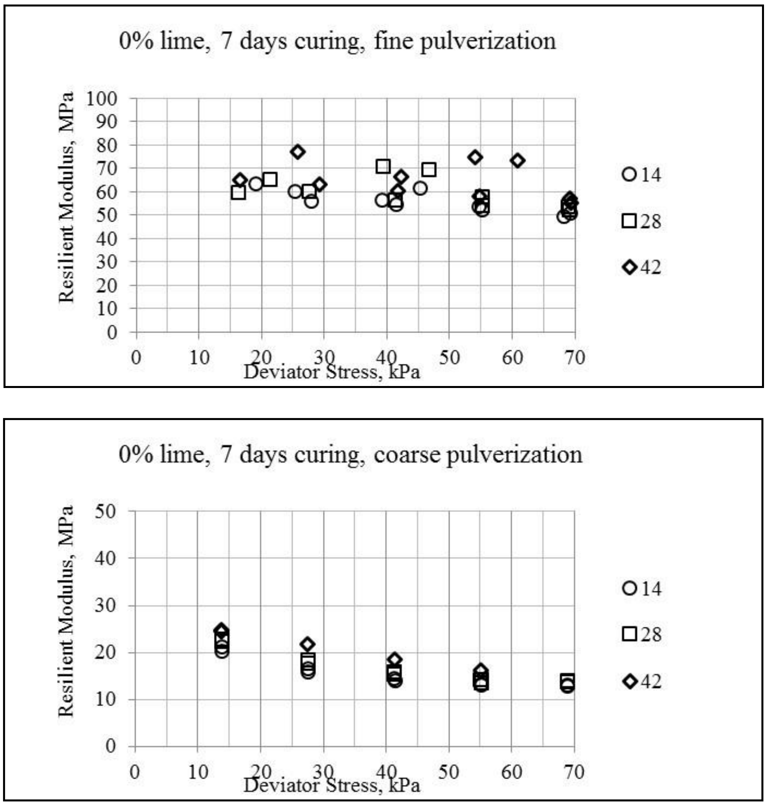


Figure 2. Resilient modulus values for 0% lime stabilization for 7 days curing

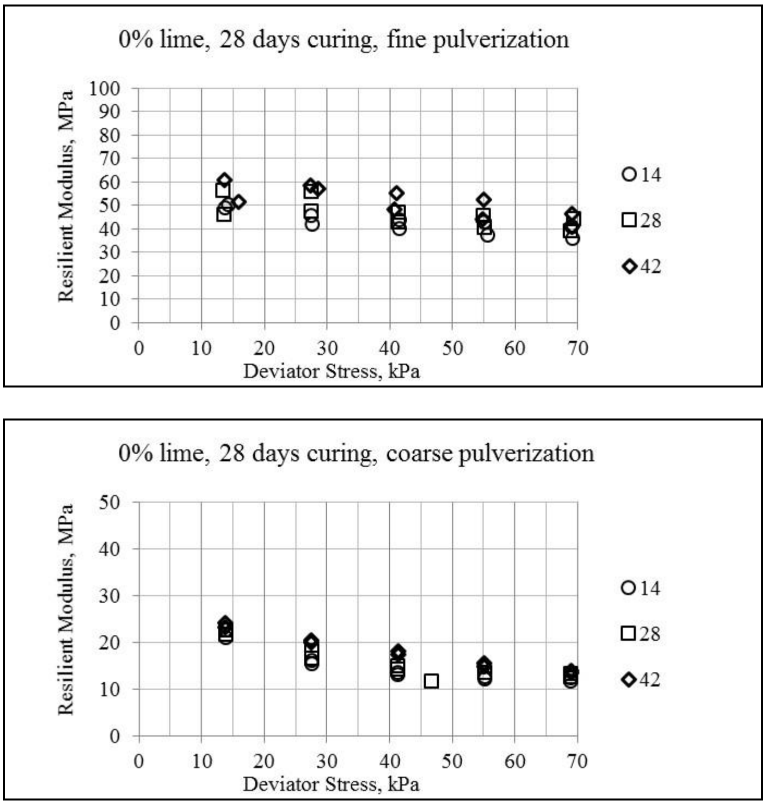


Figure 3. Resilient modulus values for 0% lime stabilization for 28 days curing

As a summary, for unstabilized soil, resilient modulus values depended strongly on soil pulverization level. For finer pulverization, the results were much higher than their coarse pulverization counterparts. The minimum resilient modulus value obtained was 10 MPa, which can be accepted as a lower bound for this soil taking into account all stress states, soil pulverization levels and curing days.

4.2. 4% LIME STABILIZED SOILS (4% lime)

In this section, results of 4% lime stabilized samples are presented in Figures 4 and 5. For 7 days curing, the resilient modulus values were found to increase with 4% lime stabilization compared to unstabilized counterparts for each pulverization level. For both pulverization levels, resilient modulus did not decrease with increasing deviator stress values. Nearly for all deviator stresses, confining stress of 42 kPa revealed somewhat higher resilient values. For fine pulverization, the values were as high as 250 MPa. On the other hand, the values obtained for coarse pulverization was 100 MPa as a maximum value. Therefore, soil pulverization level affected the results considerably.

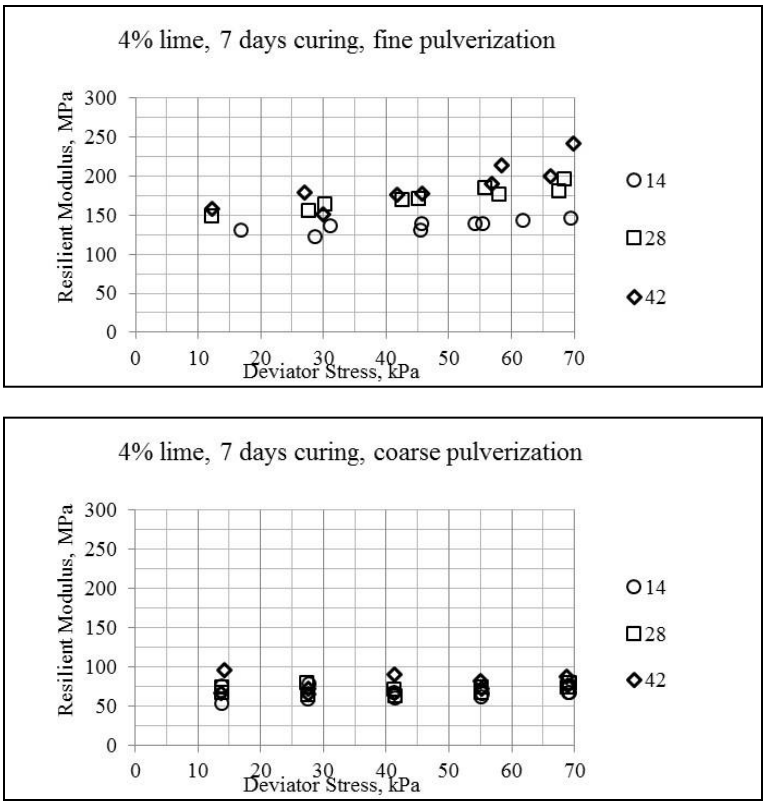


Figure 4. Resilient modulus values for 4% lime stabilization for 7 days curing

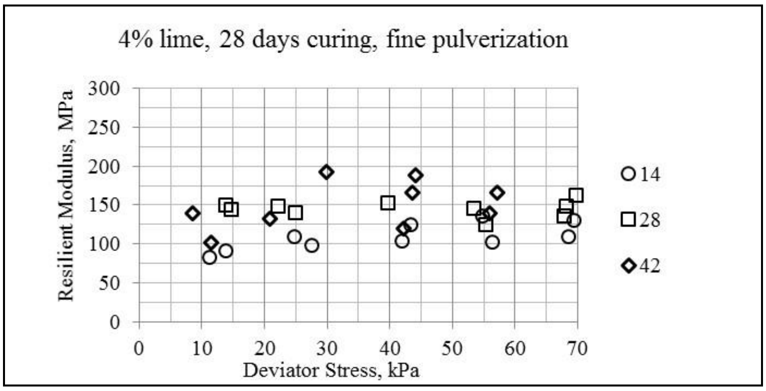
For 28 days, confining stresses affected the resilient values for both pulverization levels slightly. Increasing the deviator stresses did not decrease the modulus values. On the other hand, soil pulverization levels changed the values of resilient modulus. For fine pulverization, the values ranged between 75-200 MPa. For coarse pulverization, the values were between 50-100 MPa.

To summarize, it is clear that 4% lime stabilization changes resilient modulus-deviator stress behaviour of unstabilized high plasticity clay. Resilient values increased significantly with 4% lime stabilization. For unstabilized soils, increasing deviator stresses decreased the modulus values, however, for 4% lime stabilization, this kind of softening behaviuor was not observed.

4.3. COMPARISONS AND EVALUATIONS

In this section, some comparisons are made to clarify the differences. Figure 6 shows all samples for 7 days curing. The results are very interesting to show that, in case soil pulverization is not fine, 4% lime stabilization can not be beneficial. In other words, if soil is not fine pulverized before lime addition, the modulus values for 4% lime stabilization are very similar to those for unstabilized soil and fine soil pulverization.

Figure 7 shows the lime stabilized samples together for 28 days curing in Figure 7. After 28 days, fine pulveriation still resulted in higher values than coarse pulverization. This was valid for all deviator stresses. As an average, the ratio of modulus values obtained with fine pulverization and coarse pulverization is about 2. This is a big difference in terms of performance. This meant that, the gap between the performances do not close after prolonged curing.



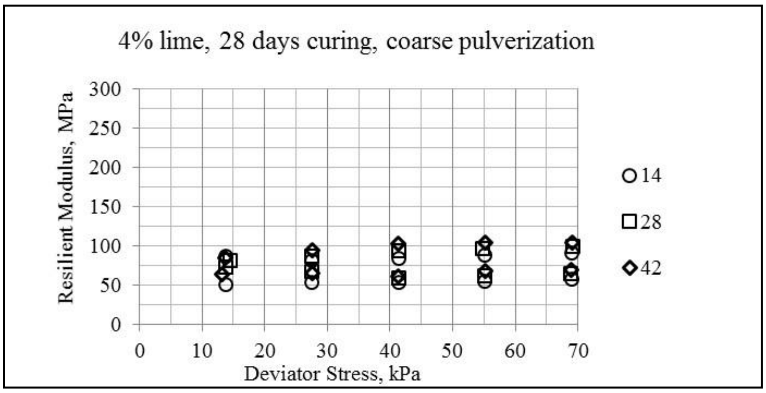


Figure 5. Resilient modulus values for 4% lime stabilization for 28 days curing

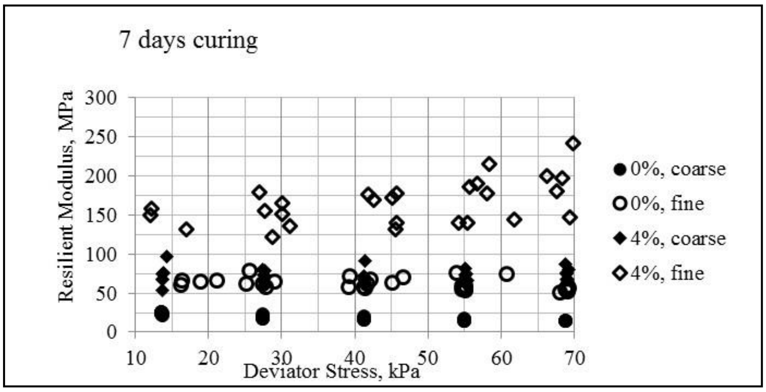


Figure 6. Comparison of Resilient modulus values for 7 days curing

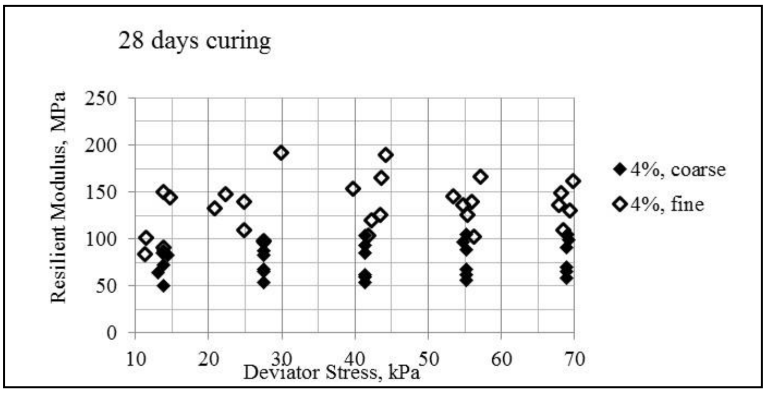


Figure 7. Comparison of Resilient modulus values for 4% lime stabilization for 28 days curing

In Figure 8, effects of prolonged curing for coarse pulverization was investigated. As evident from the figure, prolonged curing increased the modulus values at higher deviator stresses. When compared with 7 days curing, resilient modulus remained high for high deviator stresses with 28 days curing. This may be explained by the possibility that coarse pulverization needed higher curing time as compared to fine pulverization. This is probably due to the fact that time is needed for lime to reach all the clay particles and form a stable structure.

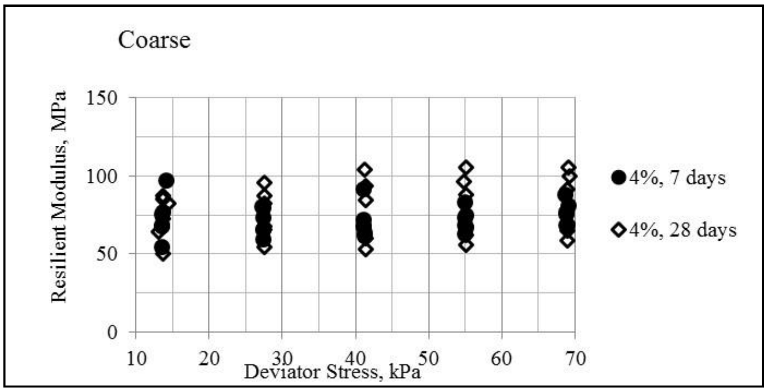


Figure 8. Comparison of Resilient modulus values for coarse pulverization for 7 and 28 days curing

5 CONCLUSIONS

This study presents the preliminary results obtained in a project carried out to determine the effects of lime on resilient modulus values on a high plasticity clay. Lime increased the resilient values considerably. The level of improvement depended on soil pulverization level significantly. Stress state and curing time were also very important parameters.

It is clear that lime stabilization can be used to enhance the engineering properties of high plasticity clays. This will certainly increase the pavement performance and it be considered as a valuable tool in terms of economic and environmental issues. However, the results presented in this study show that the level of improvement depends on the curing time, stress state in the pavement and soil pulverization level considerably. Therefore design of pavements should take into account these parameters, otherwise, performance of pavements with lime stabilized layers may not reach expected levels.

It should also be recalled that resilient modulus is not only important parameter in pavement design. Strength, durability during freeze and thaw, wetting and drying cycles are important factors which should be examined. Experiments are being carried out within the context of our project to determine these effects and to bring a comprehensive look into the behaviour of lime stabilized clays.

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