THE EFFECT OF COMPACTION FOR A LIME STABILIZATION APPLICATION

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Abstract- Lime stabilization is a very useful and economical method for fine grained soils particularly clay type of soil for earthfill of roads or structures. Lime has been used for many years to stabilize road embankment fill layers and the soil beneath the structures in the building sites. Lime stabilization is used primarily to upgrade poor quality clay soils in order to provide adequate subgrade support. The objective of the research is to investigate the effect of compaction for a lime stabilization application in the field. Geotechnical tests were conducted to determine the properties of the natural clay samples, including classification tests and California bearing ratio (CBR) tests. The optimum lime content by weight was determined as 3 % using the Eades and Grim pH method and Atterberg limits. Modified Proctor tests were conducted to determine optimum water content and maximum dry density of the soil. Maximum dry density values decreased, optimum water content values increased, and Proctor curves becomes flatter with the addition of lime as expected. Soaked CBR test results demonstrate the effect of lime stabilization. Soaked CBR value of natural soil was found as 4 %, this value increased to 60 % with 3 % of hydrated lime. Swelling during the soaking process was also decrease from 5.3 % to 2.4 % after 1 day curing. The density and water content values were measured in the field by nuclear Troxler surface moisture-density gauge. Plate loading tests in the field also shows the performance and the effect of relative compaction over the strength properties of lime stabilized soils. In place stabilization with lime reduce the need for "cut and fill" during construction works, thereby reducing environmental impacts of earthfill works.

Keywords- Clay; Stabilization; Lime; Hydrated Lime: Compaction, CBR, Plate Loading Test

I. INTRODUCTION

In the road construction works, there is much need for soil fill material in the construction of road pavements. When a section of the road is to be filled with a suitable soil, the material is either obtained from various cut sections from the road or from a borrow site where the suitable material is present, if the fill material from the road does not meet the required standards. A major cost that would be incurred by "borrowing" soil material is that involved in hauling the material from the borrow site to the construction site[1] .

Lime stabilization is one of the most commonly applied soil improvement techniques in the world. As a result of lime stabilization, clay particles stick to each other and form larger particles [2]. The following changes are observed in the soil in short term: optimum water content values increase, Proctor densities decrease and becomes flatter, plasticity indices reduce, and soaked CBR values increase sharply. Based on the studies conducted by Thomson [3], lime has been found to reduce the plasticity indices of the clayey soils and has further been determined to transform the soil into a structure that could be worked on more easily. Newbauer and Thompson [4] have found changes in the water content–density relationships as a result of the reactions between the lime and the soil. They have also found that the optimum water contents of the lime-stabilized soils were higher when compared to that of the natural clay type of soils. There are four factors that creates a stress increase in soils after lime addition. These factors could be stated as follows: the formation of calcium hydroxide crystals that behave like cement; the exchange of calcium ions found in lime with other ions found in clay's surface and the resulting amplified attractive forces between clay particles that results in larger clay units; the calcium carbonate formation and the formation of calcium silicate and calcium aluminate, which behave like cement minerals as a result of the reactions between the clayey soils and lime. Silica and alumina in soil are released and react with calcium from the lime to form calcium-silicate-hydrates (CSH) and calcium-aluminate-hydrates (CAH) [5], [6] which are cementitious products similar to those formed in cement. They form the matrix that contributes to the strength of lime-stabilized soil layers. As this matrix forms, the soil is transformed from a sandy, granular material to a hard, relatively impermeable layer with significant load bearing capacity. The process begins within hours and can continue for years in a properly designed system.

One of the objectives of this research was to investigate the effect of compaction for a lime stabilization application in the field. The other one was to demonstrate the effect of lime stabilization of an existing village road surface coating.

II. METHODOLOGY

In the study, the lime stabilization application was conducted in an existing village road with a low bearing capacity soil around Menderes town of İzmir Turkey. At the beginning, soil samples were taken

from the uppermost layer of the road and the geotechnical properties of natural soil were determined in the soil mechanics laboratory.

Geotechnical tests were conducted to determine the properties of the natural clay samples; including classification tests and California bearing ratio (CBR) tests. The optimum lime quantity for soil was selected as the minimum lime percentage in weight that produced the suitable soaked CBR values necessary for the embankment fill works specifications. Atterberg limit tests and pH tests were also conducted at various lime contents between 0 and 6% to determine the optimum lime content of the existing soil in the road base. The optimum lime content by weight was determined as 3 % using the Eades and Grim [7] pH method and Atterberg limits. Modified Proctor tests were also conducted to determine optimum water content and maximum dry density of the soil. The summary of the tests are showed below in the Table 1. The soil is classified as low plasticity clay according to the unified soil classification system.

The soil becomes non-plastic at 3 % of lime by weight. Calcium hydroxide type of lime was used for the stabilization process in the laboratory and in the field application.

Table 1. Typical geotechnical properties of the soil

		Natural	3% lime
	Unified soil classification	CL	-
Atterberg Limits	Liquid Limit, LL (%)	33	NL
	Plastic Limit, PL (%)	20	NP
	Plasticity index, PI (%)	13	NP
Sieve anaysis	passing 4,74 mm (%)	68	-
	passing 2,0 mm (%)	66	-
	passing #200 sieve (%)	54	-
California Bearing	Curing: room + soaked (days)	0+4	1+4
Ratio CBR (%)	CBR 2.5 mm (%)	4,0	34,9
	CBR 5 mm (%)	4,0	60,5
	CBR Final (%)	4,0	60,5
	Swelling (%)	5,3	2,4
Modified Proctor Test	Max. Dry density (gr/cm^3)	1,97	1,88
	Max. Dry unit weight (kN/m^3)	19,3	18,4
	optimum water content w(%)	6,15	6,32
Natural water content	w_n(%)	6,23	

CBR test is very important test to determine the fill material performance under saturated conditions. CBR test results show very sharp increase with lime, the CBR value of natural soil was found as 4 % but the soil with 3 % of lime increases to 60 % which is a very high value for this kind of soils. After the validity of the lime stabilization was proved in the laboratory, the lime application was applied on the existing soil at 30-35 cm depth. Although natural water content was around the optimum, lime uses water for the chemical reactions. Watering was applied after mixing the existing soil with calcium hydroxide in powder form. And finally, compaction has been done to bring the stabilized soil to the expected relative compaction values.

III. LABORATORY TESTS

A. pH method for design lime content

Determining the amount of lime necessary is part of the design process and is approximated by tests such as the Eades and Grim test [7]. A sufficient or optimum amount of lime shall be added to soils to produce a pH of 12.4 or equal to the pH of lime itself which enables the clay particles to break down. An attached graph is plotted showing the pH as lime content increases.

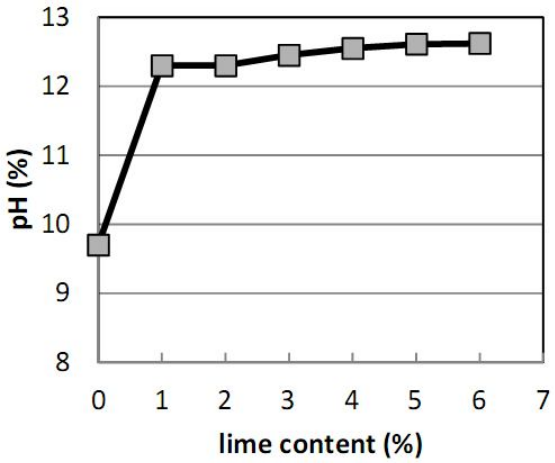


Fig. 1 pH values at various lime contents

In the graph above, pH of the lime-soil mixture reaches to 12.4 at 3 % of lime. The design value is finally chosen as 3 % by weight. This value also demonstrated by using performance tests such as CBR test.

B. Atterberg Limits

After adding lime to the soil with water, structural transformation and flocculation begins immediately and initial plastic properties of the soil changes in an hour. In the research, dry soil was initially mixed with lime and then the Atterberg limit tests were conducted after 1 hour waiting time for initial reactions. The tests were conducted in accordance with ASTM 4318[8] . For the Atterberg limit tests 3 % of lime was used found from pH tests. Based on the Atterberg limits conducted, it was seen that, the soil structure was changed and the soil becomes non-plastic. These results also demonstrate that the design lime amount as 3% by weight is an economical and effective amount for the soil.

C. Modified Proctor tests

Moisture and density relations of the soil were determined using modified Proctor compaction tests. The tests were conducted according to the ASTM D 698-78 and D 1557-78 [8]. Following these tests, comparisons were made of the behavior of the lime stabilized soil with natural conditions. The tests were performed with after waiting for 1 hr. to let the first reactions to take place upon mixing at the determined

amount of lime and water to the natural dry samples. The modified Proctor tests were conducted with natural soil and soil with 3 % of lime. The results of the tests were shown in Fig. 2 below.

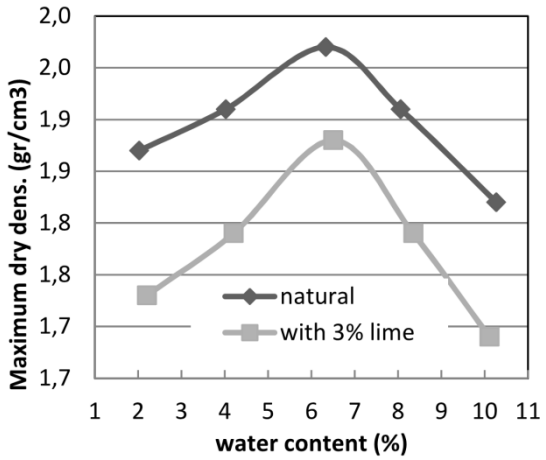


Fig. 2 Modified Proctor test results

The original water content of the soil in the field was found as 6.23 % which is close to optimum water content which is 6,15 % of natural clay as shown above. The optimum water content increased to 6,32 % with lime as shown in Figure 2. It shows that the maximum dry unit weight (MDUW) decreases from 19.3 kN/m3 to 18.4 kN/m3 with 3 % lime. Optimum water content of the soil increase while the maximum dry unit weight (MDUW) of the soil decrease with 5% lime by weight.

D. California Bearing Ratio tests

California bearing ratio tests were conducted according to the ASTM D 1883-87 [8] for soaked cases. Experiments have been done on both of natural soil samples and compared with lime compacted at natural water content. Swelling during the soaking process was also decrease from 5.3 % to 2.4 % after 1 day curing. CBR values were calculated from the figure below by using 2.5 mm and 5 mm deformation values.

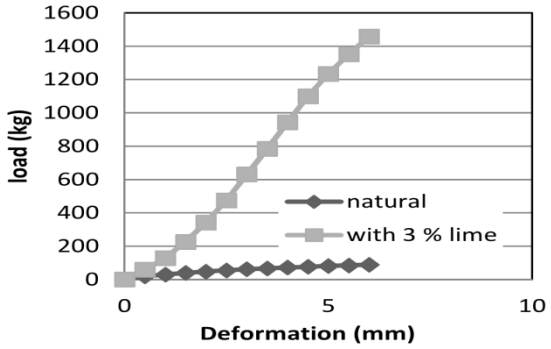


Fig. 3 *CBR* tests for natural soil and stabilized soil

California bearing ratio (CBR) values for soaked samples increased from 4% initially to 60% with lime, due to reduced swelling of the clay.

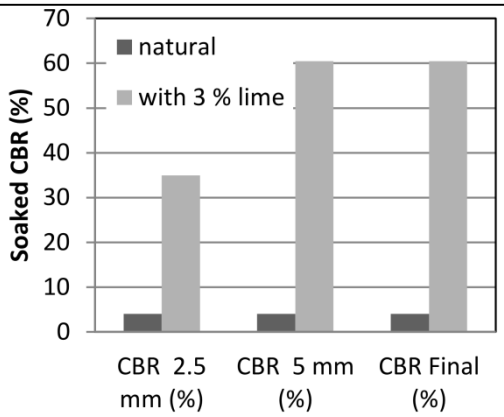


Fig. 4 *CBR* values for natural and lime stabilized soil

The test results show that the soil becomes suitable as earth fill for road construction at the subgrade level and beneath.

IV. FIELD LIME STABILIZATION APPLICATIONS AND TESTS

A. In situ Density Determination

Lime stabilization in the field was conducted on the existing surface of the village road which has 625 meter. The lime distributed at a uniform rate and in such a manner as to reduce the scattering of the lime by wind to a minimum. All lime was mixed with the material to be treated immediately after application of lime. The soil-lime mixture shall be sprinkled during the mixing process, to provide optimum moisture in the mixing immediately prior to starting the compaction operation. The course shall be sprinkled as required and compacted to the extent necessary to provide no less than ninety-five (95) percent of the density measured by modified Proctor test. The density and water content values were measured in the field by nuclear Troxler 3440 surface moisture-density gauge and the final relative compaction (RC) values were given below in Table 2.

Table 2 Relative compaction in field

Test	Wet Den. (gr./cm3)	Water C. (%)	Dry Den. (gr./cm3)	Rel. Com. RC (%)
1	1,99	10,8	1,80	96,2
2	1,95	8,9	1,79	95,8
3	2,07	6,7	1,94	103,5
4	1,98	6,5	1,86	99,4
5	2,07	10,1	1,88	100,7
6	2,01	5,5	1,90	101,8
7	1,92	7,4	1,78	95,4
8	1,92	7,4	1,79	95,7
9	2,05	12,5	1,83	97,6
10	2,02	7,4	1,88	100,6
Average		8,3		98,7

In the field density tests, water content varies within 5.5 to 12.5. The average water content was found as 8.32 % and this value is 2 % over the optimum water content. Usually it is a good case for water content to be a little bit higher than optimum, since lime stabilization needs more water for future cementation reaction. Average relative compaction value was found as 98.7 which one is over 95 %. All the RC values satisfy this criteria and it can be said that the lime stabilized fill layer compacted satisfactorily.

B. Plate loading tests

The effect of lime stabilization and the strength of the road layer on were analyzed by Plate loading tests (PLT). The experiments were performed with 30 cm diameter circular plate and conducted after a few hours of compaction. The tests were completed either the stress reaches 1,000 kPa or the soil collapses [9]. The failure or collapse of the soil is the point where deformations reach to 2.5 cm in the stress-deformation graph or the soil fails with increasing deformation at the same load level.

For all the plate loading experiments conducted in situ, soil has been initially loaded to 1,000 kPa (10 kg/cm2) or collapse of the soil and then unloaded in order to make comparisons. For each stress level, it was kept waiting in each level till deformations remains constant. The selected 1,000 kPa loading was much higher than the traffic loads that would normally be exerted on the lime stabilized road surfaces. Two plate loading tests at 96 % and 100 % RC area conducted on the lime stabilized layers. Lime stabilized fill layers show a very high performance at low deformations under high stresses as shown in the figure 5 for all the tests.

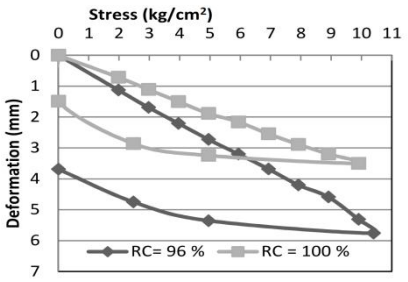


Fig. 5 PLT in the field at two relative compaction point

The elastic final deformations found in the tests were 3,5 and 5.8 mm under 1100 kPa stress level and permanent deformations become 1.3 and 3.7 mm. in plate loading tests conducted on lime stabilized fill layer. According to results, the allowable bearing capacity of the soil was found greater than 350 kN/m2 and modulus of subgrade reaction values was found greater than 172,000 kN/m3. It can be said that, relative compaction directly affects the strength of the soil as shown in the figure as it is expected. Although, both of the test results are very well, for the case at 100 % RC condition, deformation values were almost half of the 96% RC test case.

CONCLUSION

The optimum lime contents obtained from Atterberg limits and Eades and Grim pH method was found to be suitable for the soil based on the results of performance tests such as CBR and plate loading tests. As they could be conducted quickly, these two methods could be effectively used together with lime stabilization applications for preliminary design. When mixed with lime, the soaked CBR values of the soil have exhibited significant increases even at only one day curing. At the end of 5 days (1 day cure+4 days soaking period), the soaked CBR value of 3% lime added clay has increased 15 times compared to the natural state of the same material. Compaction is very important for all the compaction works. Relative compaction directly affects the strength of the soil as shown in the figure as it is expected. Although, both of the test results are very well, for the case at 100 % RC condition, deformation values were almost half of the 96% RC test case. In the short-term and long term, considering the structural contribution of lime-stabilized layers in pavement design creates more cost-effective design alternatives and lime stabilization provides performance benefits that reduce maintenance costs.

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