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Stabilization of high plasticity soil at high water content with a special hydraulic lime

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***Abstract*— Clayey and high plasticity fine grained soils usually create too much problems for earth fill works. In general, if the geotechnical properties of the existing soil are inappropriate, it is either replaced with a suitable fill material or improved on-site via various methods. This study investigated the use of lime to stabilize high-water-content high-plasticity clay for use in fill layers of an industrial region roads. Usually, drying of high-water-content clays is almost impossible at construction sites. At the beginning, MH high plasticity silt type of soil was dried first and then stabilized with hydrated lime and hydraulic lime at optimum water content and results of both lime are compared. The hydraulic lime was chosen for the real application and then, the research investigates the possibility of stabilizing high-water-content clay with a special lime called hydraulic quicklime without drying the soil.**

High plasticity soil was obtained from the Hadımköy district of Istanbul city in Turkey. Initially, Atterberg limit tests, sieve analysis and Proctor tests were performed on soil samples. The *pH* method indicted that appropriate lime content for stabilization was 3% by weight, and Atterberg limit tests were conducted at various lime contents. The original water content was 30-32%, which is very high compared to the 17% optimum water content of natural soil. The optimum water content increased to 18-21% with hydraulic lime. Hydraulic lime decreases the existing water in the natural clay soil during hydration and the water content of the mixture approaches the optimum water content of the clay soil with lime, resulting in large increases in strength of up to 14 times that of the natural clay soil. California bearing ratio *(CBR)* for soaked samples also increased from 4-6% initially to 40-75% with hydraulic lime, due to reduced swelling of the clay. The test results show that the soil becomes suitable as earth fill for road construction at the subgrade level and beneath. Quicklime additive improved the stabilization of high-water-content silty soil. Improvements to existing soils reduce the need for "cut and fill" during construction works, thereby reducing environmental impacts. This method is being applied in the field for the improvement of 550 000 m^3 of clay and the work is going on.

***Keywords*— clay, lime, stabilization, quick lime, hydrated**

I. Introduction

Clayey or high plasticity silt type soils usually create too much problems for earth fill works. In general, if the geotechnical properties of the existing soil are inappropriate, it is either replaced with a suitable fill material or improved on-site via various methods. This study investigated the use of lime to stabilize high-water-content high-plasticity soil for use in fill layers of an industrial region road called DESB. Lime stabilization is commonly used method for the stabilization of clayey soils. In result of lime stabilization, quite severe growths occur in especially strength besides the change of clay's geotechnical and plastic features. As a result of their study, Clare and Crunchley (1957) [1] and Croft (1964) [2] have determined a total of four factors that creates a stress increase in soils after lime addition into clay. These factors are the formation of calcium hydroxide crystals showing the features of cement after the lime gets into reaction with clay surfaces, the exchange of calcium ions (ion exchange) included in lime with the other ions on clay surface; as connected with this, clay particles' creation of bigger dimensioned particles called flocculation or aggregation by pulling each other, formation of calcium carbonate that is called carbonation as a result of reaction with carbon dioxide in atmosphere, and formation of calcium silicates or calcium aluminates showing the features of cement minerals that is called as pozzolanic reactions in result of the fact that clayed surfaces involve in relation with lime. First three occur immediately but the last one pozzolonic reactions occur in time. Kavak and Baykal (2012) [3] studied the long term effects of lime stabilization on the kaolinite samples. In the Fig. 1 unconfined compressive strength (UCS) tests of a lime stabilized kaolinite was shown. The unconfined compressive strength of natural kaolinite was 125 kPa; this increased to 970 kPa in one month and reached to 2640 kPa for lime-stabilized kaolinite samples cured for 123 months, which is 21 times the original value. In the long term, the unconfined compressive strength of lime-stabilized kaolinite increases continuously although the rate of increase is less in later years. Soil stabilization by lime refers to the admixture of this material in the form of calcium hydroxide (CaOH) to the soil and the compaction of the mixture at the optimum water content. These chemical processes modify the soil structure whereby larger grain aggregates are formed (Broderick and Daniel 1990) [4], leading to several advantages in the suitability of the soil for road construction. The objective of this research was to determine the possibility of lime stabilization for the high plasticity soil in the DESB industrial region for the road embankment earth fill works in İstanbul Turkey.

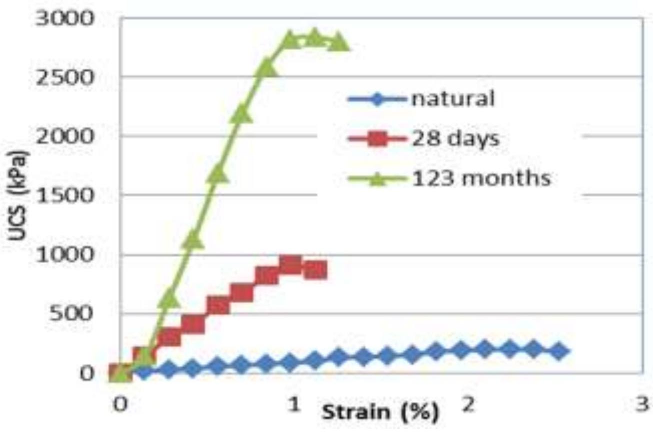

Figure 1. UCS tests for Kaolinite with 4% of lime (Kavak 2012)

The test results show that the soil becomes suitable as earth fill for road construction at the subgrade level and beneath. Quicklime additive improved the stabilization of high-water-content clayey soil. Improvements to existing high plasticity fine grained soils reduce the need for "cut and fill" during construction works, thereby reducing environmental impacts. This method is being applied in the field for the improvement of 550,000 m^3 of clay and the work is going on.

II. Methodology

The laboratory study started with sieve analysis, liquid-plastic limit analysis for the classification of the soil and later on Proctor and CBR tests were also performed to determine the typical geotechnical properties of the material for earth fill works. Geotechnical basic properties of the soil are given in Table 1. Soil was classified as high plasticity silt and soaked CBR values were found around 5 %. The natural water content of the soil was found as 32 % which is very high compared to optimum water content of the soil material.

TABLE 1. Geotechnical properties of natural soil

Classification (UC)	Natural clay	MH
Atterberg Limits	Liquid limil (LL) (%)	50,12
	PlasticLimit (%)	34,31
	Plasticty index (%)	15,81
Sieve Analysis	Passing 4,74 mm sieve (%)	84,36
	Passing 2,0 mm sieve (%)	80,91
	Passing 200# sieve (%)	66,68
CBR	Soaked CBR (%)	5,59
	CBR swell (%)	2,95
Modified Proctor	Max. Dry unit Wgt. kN/m3	16,25
	optimum water c. w(%)	16,02
Natural water c. (%)		32,00

In the next stage, the lime amount to be used in the stabilization process was determined for preliminary design lime percent. Eades and Grim (1963) [5] *pH* method and Atterberg limits (Kavak and Akyarlı 2007) [6] were used for the determination of optimum lime content by weight. The tests are done by using both of the lime and hydraulic lime

TABLE 2. pH values at various lime contents

Lime Content (%)	Lime	Hydraulic Lime
0	8,50	8,50
1	12,58	11,91
2	12,61	12,29
3	12,66	12,55
4	12,67	12,58
5	12,69	12,62
6	12,70	12,63

pH of the natural soil was found as 8.5 and pH increases with lime percent as shown in Table 2. Eades and Grim methods define the optimum lime content as the lime amount that brings the soil to pH=12.4. According to this methodology pH value pass 12.4 by 1% of lime and 3 % of hydraulic lime.

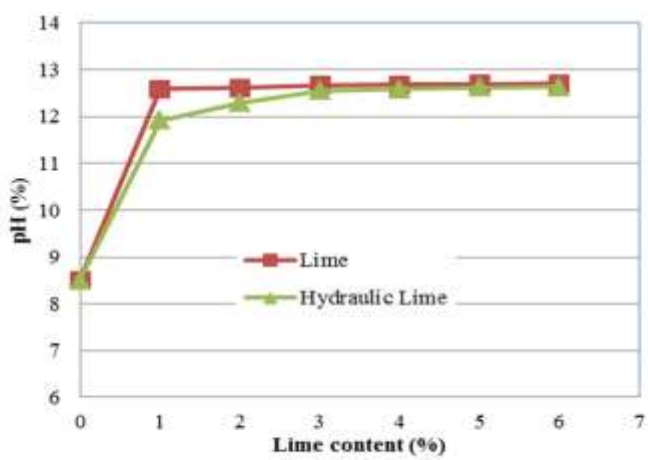

Figure 2. pH values at various lime contents

III. Results of Tests

A. Atterberg Limits

Liquid and plastic limit tests were conducted on the samples by mixing different amounts of lime to the materials. After adding lime, structural transformation and flocculation begins immediately. Soil was initially mixed with lime and was then kept under curing conditions for one hour [6] before Atterberg limit tests were performed. The tests were conducted in accordance with ASTM 4318. Lime amounts were chosen as 2 and 3% for both of lime and hydraulic lime by using the pH data. These lime contents were calculated using the dry weight of soil and the lime content were used by weight in the study. According to the results of Atterberg limit tests, liquid limit value does not change significantly with lime but plastic limit values increases with lime content as shown in the Fig. 2. Based on the experiments conducted, it was seen that as the amount of lime in the mixture was increased, substantial reductions in PI values were observed. Plasticity index values become less than 10% at 3 % for both of lime and hydraulic lime.

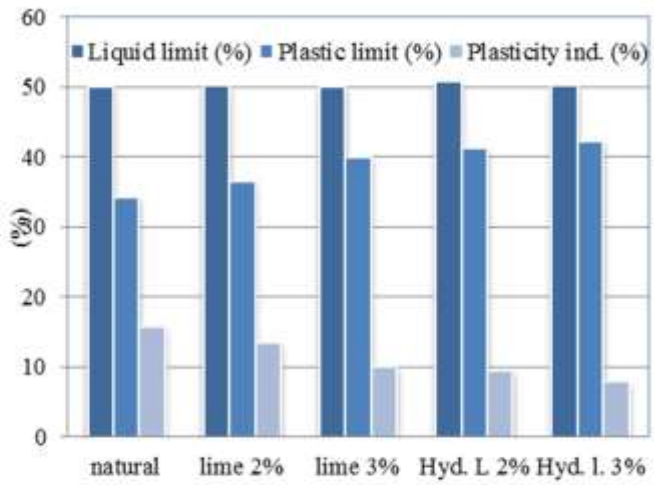

Figure 3. Atterberg limits with lime and hydraulic lime

Hydraulic lime was found as more effective than hydrated lime. Plasticty index becomes 7.95 with 3 % hydraulic lime.

TABLE 3. Atterberg limits with lime and hydraulic lime

Atterberg Limits	natural	lime 2%	lime 3%	Hyd. L 2%	Hyd. l. 3%
Liquid limit (%)	50,12	50,19	50,05	50,91	50,31
Plastic limit (%)	34,31	36,63	39,92	41,37	42,36
Plastic.Index(%)	15,81	13,56	10,13	9,54	7,95

The optimum lime amount was jointly determined by using of the lime amount that reduced the plasticity index value below 10% with 1 h Atterberg limit method and the lime amount that increased the pH value to 12.4. When the changes in the plasticity index values, the pH values and the economies were considered, the optimum lime amount was selected to be 3% by weight for both of the lime types. Hydraulic lime was chosen for the application in the field, because of plasticity index values were smaller compared to Ca(OH) lime.

B. 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 (Bowles 1992) [7]. Following these tests, comparisons were made of the behavior of the lime stabilized soil with natural conditions. The experiments were performed after waiting for 1 h to let the first reactions to take place upon mixing the determined amount of lime and water to the natural dry samples.

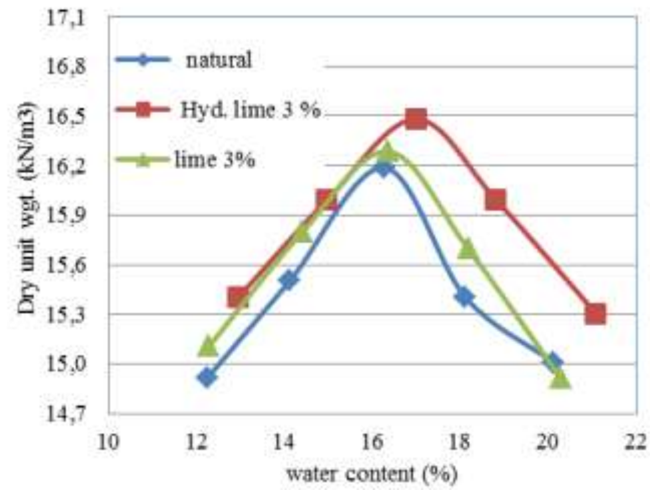

Figure 4. Modified compaction tests

Optimum water content increases with lime and it reach to 17.5% which is 1.5% more than the original soil water content. This case is very good for the applications in the field because lime dries the soil and increases the optimum and therefore workability of the soil increase during the earth fill works in the field.

C. California Bearing Ratio tests

California bearing ratio tests were conducted according to the *ASTM D* 1883-87 [7] for soaked cases. Experiments have been done on both of samples natural soil, with lime and hydraulic lime. The samples have been prepared first by mixing at optimum water content and leaving an hour in the laboratory for initial reactions then compacted in *CBR* mold. Then, the samples were cured at room temperature for 0 and 3 days and kept waiting in water for 4 days. The swelling amounts in the lime stabilized soil samples were found to be below 1%. The results of soaked *CBR* tests were shown in Fig. 5 below.

For Soaked tests, the *CBR* of natural soil was found as 5%, this value reached to 75 as maximum with 3% of hydraulic lime in 3 days, which one is approximately 15 times higher than the original value. The similar sharp increases are also observed for the uncured soaked samples cured samples with 3% of lime as shown in the Fig. 5.

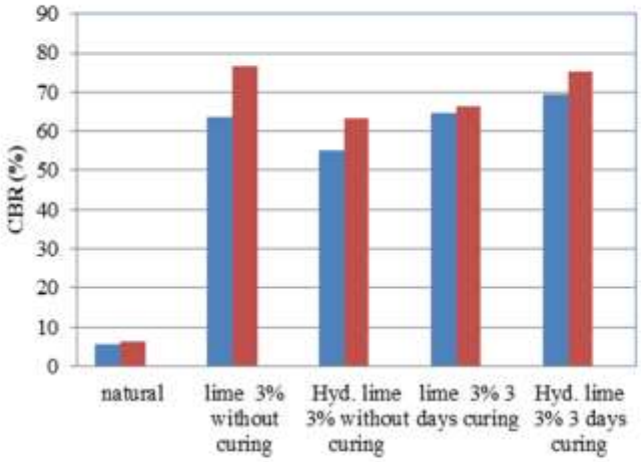

Figure 5. Soaked *CBR* test results

IV. Lime Stabilization application in the field

Lime stabilization application was started in DESB industrial region after the preliminary laboratory work. Hydraulic lime was chosen at 3% by weight for the lime stabilization application by taking care of pH tests, Atterberg limits and soaked CBR tests. Hydraulic lime were better

A. Plate loading tests

The effect of lime stabilization on the road was analyzed by plate loading tests. The experiments were performed with 30 cm diameter circular plate. The tests are completed and either the stress reaches 1,000 kPa or the soil collapses (Kavak 2007) The failure or collapse of the soil is the point where deformations reaches and passes 2.5 cm in the stress-deformation graph. In all the plate loading experiments conducted, all samples were initially loaded to 1,000 kPa 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 stopped. The selected 1,000 kPa loading was much higher than the traffic loadings that would normally be exerted on the lime stabilized road surfaces. Two plate loading test conducted on the lime stabilized layer were shown in Fig. 6.

The tests results were usually similar. Lime stabilization fill layer shows a very high performance under high stresses as shown in the figure. The elastic deformations found were around 3 mm under 1100 kPa Stress and permanent deformations become 0.9-1.4 mm. interval.

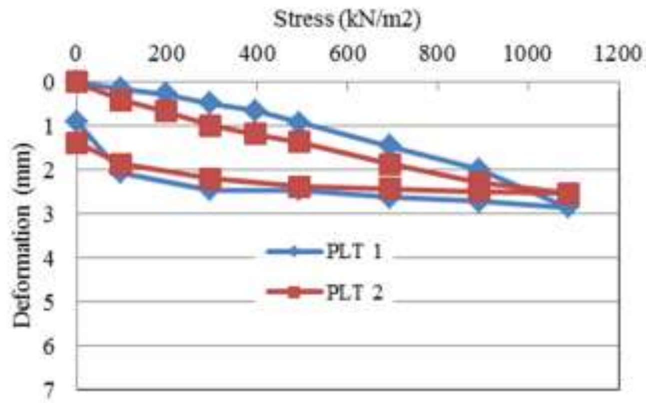

Figure 6. Plate Loading tests on lime stabilized fill

According to results, the allowable bearing capacity of the soil was over 500 kN/m^2 and modulus of subgrade reaction values was around 300,000 kN/m^3

V. Conclusion

The study and lime stabilization application became satisfactory for the improvement of high water content fine grained Hadımköy/Istanbul soil. Since the water content of the natural soil was very high which is 32% compared to optimum water content at 16%, generally, it is almost impossible to use these material in the earthfill works in the field without drying or modification. Hydraulic lime dried the soil, and water content of the mixture becomes 21-24% after the compaction and drying continue in time. Hydraulic lime was applied in the field both as hydraulic lime and hydraulic quicklime. Particularly in winter hydraulic quicklime was used for the stabilization process.

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 hydraulic lime, the soaked CBR values of the soil have exhibited significant increases. At the end of 7 days (3 cure+4 days soaking period), the soaked CBR value of 3% hydraulic lime added clay has increased 15 times compared to the natural state of the same material. Similarly, the soaked CBR value of samples taken from the application field after lime stabilization process at 3% hydraulic lime as average has increased 8 times compared to the natural state of the same material. The swelling values of soil were below 1%. Based on these results, there will be reductions in the thickness of road pavement.

This application had many operational and environmental benefits for the region in Istanbul. In the field probably

950,000 m^3 soils will be stabilized inside the construction field that means around 120000 truck movements will not occur in the Istanbul city. Carbon emission, machinery, traffic and quarry damages will be less compared to the classical methods.

Acknowledgment

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About Author (s):

The most importing theme of these paper was to create data about high water content soil and the probability of mixing in the field. Another was the lime type.