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The Influence of High Plasticity and Expansive Clay Stabilization with Limestone on Unconfined Compression Strength

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ABSTRACT Clay is a cohesive material that becomes very soft when high content of water is added. This condition makes construction activities difficult on this type of soil. There is, therefore, a need for stabilization when dealing with high plasticity clay through several methods such as the application of limestone. However, this method mostly does not meet the standards due to the reaction between limestone and groundwater which normally alters soil properties, thereby, leading to a reduction in stickiness and softness of the soil. Meanwhile, limestone generally has the ability to compact and stabilize the soil due to its fine powder which consists of metals and non-organic mineral compositions. Therefore, this study was conducted to identify the influence of using limestone additives for stabilization at different mixture compositions on clay. The properties of the soil were tested before the Unconfined Compression Strength Test and the results showed limestone was effective in stabilizing high plasticity and expansive clay. This was proven by the 10% increase in the Unconfined Compression with lime content in curing conditions for 28 days as well as the 319% magnitude of the non-soaked, 6% reduction in the liquid limit value, and 46% increment in the plastic limit value.

KEYWORDS High plasticity clay; Unconfined compression strength; Limestone; Expansive clay; Stabilization.

1 INTRODUCTION

Clay is a type of soil which has the ability to absorb air easily and to expand (Hotineanu et al, 2015). High plasticity clay can damage the structures constructed on it. Therefore, some additional materials such as limestone are usually added to improve the soil. The addition of a small percentage of lime binder to fill clay soil became a popular soil improvement technique in Great Britain in the 1970s (Notman, 2011). This is due to the ability of lime to reduce the plasticity, increase the workability, reduce the swelling, and increase the strength of medium to high plasticity clay. Lime is also used in stabilizing different materials such as weakly alkaline soils which it turns to "workbenches" or subbases as well as a marginal granular base material known as gravel-clay or "dirty" gravel to form a strong and high-quality base layer (Guyer, 2011). Several studies have been conducted on the mechanism of the basic lime-clay reaction (Balaji et al, 2018; Beetham et al., 2015; Bessaim et al, 2018; Devi et al, 2018) Meanwhile, there are several techniques to improve and stabilize soil properties including the addition of lime (Ali and Mohamed, 2017; Bell, 1996; Garzón et al, 2016). One of the most common methods is remediation which is usually applied due to its facilities and economic appearance as well as the effectiveness in producing engineering materials with superior properties. The wide reports on the basic mechanism of the lime-clay reaction in previous studies lead to a better understanding of the physicochemical evolution of the system and the microstructural features induced after lime addition.

Pore fluid can also be modified with chemicals through the addition of lime (CaO). The first reaction in this process is hydration which is highly exothermic and usually leads to the formation of hydrated lime in the groundwater system. This happens based on the dissociation reaction caused by the increase in pH and the high concentration of calcium ions in the water pores as a result of the hydration. This phenomenon further leads to several reactions in the soil matrix (Cheng et al., 2018; Gilazghi et al, 2016); (Aldaood et al, 2014, Al-Mukhtar, 2010). These include cation exchange which causes a decrease in the thickness of the bilayer around the clay particles due to the tendency of the calcium ions released from the lime to displace the exchangeable clay cations. This, therefore, allows the stabilization of the clay particles and improvement in their properties such as plasticity and compaction parameters. Moreover, the exchange also causes clay minerals to flocculate and agglomerate, and this usually leads to rapid changes in plasticity, workability, and particle size distribution (Leroueil and Le Bihan, 1996; Wibisono et al, 2018).

In this research, clay soil with uncontrolled strong pressure was stabilized by compacting the soil with different density at a certain water content. This was followed by different preservation processes with different variations of copper and cement slag content. Meanwhile, the cylindrical specimens stabilized with copper slag and cement were used in the strong free compression method. This was due to the ability of copper and cement slag added to increase the strength of soft clay and high comprehensiveness. The overall test results showed copper and cement slag was effective in stabilizing the soil with the increase in compressive strength observed not to be significantly limited. This, therefore, means there are relatively good strength predictions from the compilations of strength based on the availability of several reliable data. The test results also showed the possibility of using the free compressive strength method in determining quality control and stabilization work assurance (Jadhav, 2016).

2 LITERATURE REVIEW

The improvement of soil properties through the addition of certain materials is called soil stabilization. This soil control method is usually applied to achieve the desired gradation using the additives with the ability to change the gradient, texture, or plasticity, and also to bind the soil (Langdon, 2009). Soil stabilization aims to improve or change soil technical properties such as the carrying capacity, compressibility, permeability, workability, swelling potential, and sensitivity to alteration of water content (Hardiyatmo, 2010). The methods are, however, generally divided into three stages:

a) Mechanical stabilization: This is the process of mixing two or more soils with different gradations to increase the strength and durability of soil aggregates (Hardiyatmo, 2010). It is usually conducted without the addition of foreign materials. It also improves soil properties by reducing soil volume, drainage, and maintaining moisture content at a constant level. The method also involves mixing several soil types (Kezdi, 1967).

b) Physical Method: The practical physical properties which cause stabilization include the changes in temperature, hydration such as the bondage and hardening in Portland cement, evaporation as indicated in the drying of bituminous emulsion reinforced soil, and adsorption (Kezdi, 1967).

c) Chemical Stabilization: This involves mixing the soil with additional materials to improve its technical properties (Hardiyatmo, 2010). Some of the materials usually added include asphalt, cement, lime, fly ash, chemicals, salt, and several others (Guyer et al, 2011; McCarthy, C et al, 2014) Clays were observed not to be good for construction are usually stabilized through the application of lime. Substrate shrinkage or swelling specifically has the ability to damage engineering structures. Therefore, clays with a liquid limit (WL) greater than 90% or plasticity index (IP) higher than 65% are not suitable to be used as a filler for soil. Lime addition is a quick improvement to the engineering properties of the soil and has two sides. The first is related to the conditioning of water content to achieve optimal quantity in the compaction process. The second is focused on the chemical changes in the surface of clay particles and this reduces the potential for changes in the mineral volume of the clay.

High plasticity clay soil is consistently in the range of water content with a large plastic area. Meanwhile, a greater range usually reduces the land in terms of strength and causes a continuous increase in shrinkage (expansive). The relationship between plasticity index, expansion potential, shrinkage, and expansion rate are, therefore, presented in Tables 1 and 2.

Table 1. Relationship between plasticity index and swelling potential (Chen, F. H., 1975)

Plasticity Index (%)	Swelling Potential (%)
0-15	Low
10-35	moderate
20-55	high
35 more	Very high

Table 2. Relationship between the percentage of Atterberg shrinkage, linear shrinkage, and degree of expansion (Chen, F. H., 1975)

Shrinkage Atterberg (%)	Linear Shrinkage (%)	Degree of Swelling
< 10	> 8	Critical
10 -12	5-8	Moderate
>12	0-5	Not Critical

The addition of a larger lime binder during the initial consumption of lime (ICL) and the BSI pozzolan reaction between lime and clay has the ability to substantially cause long-term improvement in technical properties such as strength, durability, and ice resistance (Eades and Grim, 1966). Meanwhile, the pozzolanic reactions were reported to be slower and require months or even years to develop. Pozzolan is like blast furnace slag grains and this means they are preferred when greater strength is required quickly such as within 7 days using only lime (Wilkinson et al, 2010).

It is possible to improve soil characteristics chemically through the use of lime. The reaction normally starts with mixing which can last for decades. The application of this method in soil stabilization using lime, however, involves reduction of water content, cation exchange coagulation, pozzolan cementation reaction, and carbonation of lime.

3 METHODS

The soil samples used in this study are damaged soils collected at a depth of approximately 0.5 to 1 m. Their physical properties are summarized in Table 3 and the soils can be classified as high plasticity (CH) clay according to the Soil Classification System.

Table 3. Physical properties of the samples

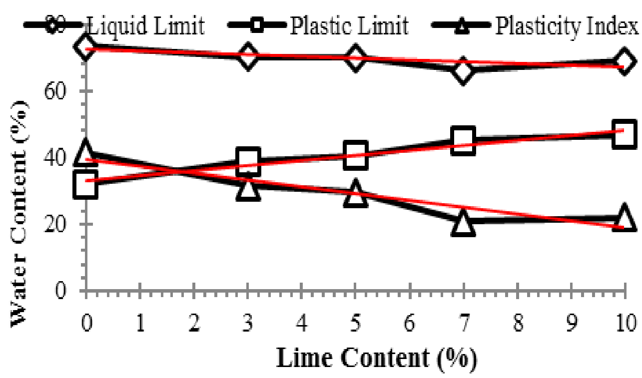
Properties	Soil 1	Soil 2
Clay Fraction (%)	61	65
Silt Fraction (%)	37	33
Sand Fraction (%)	2	2
Liquid Limit (%)	73	63
Plastic Limit (%)	32	23
Plastic Index (%)	41	40
Specific Gravity	2.74	2.67
Soil Classif. (USCS)	CH	CH
MDD (kN/m^3)	13.40	14.30
OMC (%)	32.30	22.80

4 RESULTS

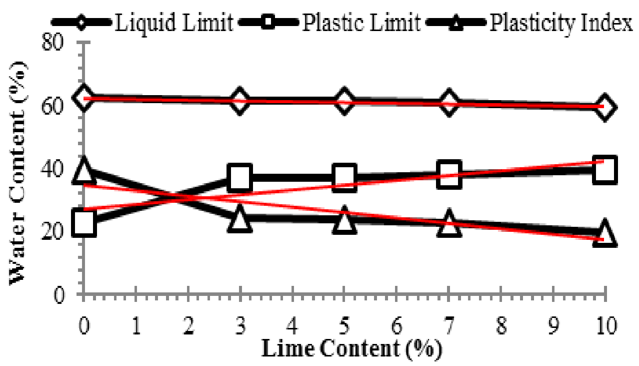
The results are discussed under two subsections which are the effect of lime on the Atterberg limit and the UCS test under several conditions.

4.1 Influence of Lime on Soil Samples at Atterberg Limit

Atterberg limit of lime-mixed soil was used to determine the effect of the lime content added to the consistency value and the results are displayed in Table 4 and Figure 1.



a) Soil sample 1



b) Soil sample 2

Figure 1. Effect of lime addition on the Atterberg limit of soil samples 1 and 2

Table 4. Atterberg limit test result

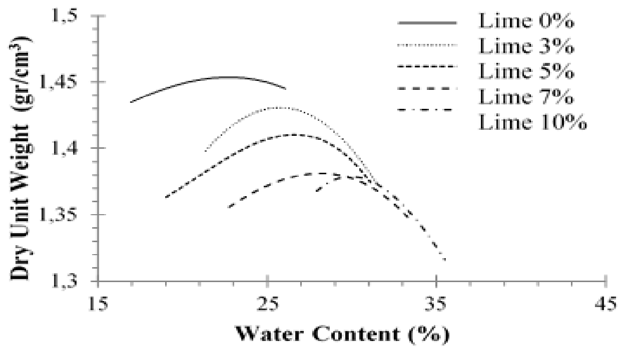
Atterberg Limit	Lime Content (%)				
Soil 1					
	0	3	5	7	10
LL	73.43	70.24	69.90	65.98	68.93
PL	32.06	38.86	40.39	45.21	46.85
PI	41.37	31.38	29.51	20.77	22.08
Soil 2					
	0	3	5	7	10
LL	62.33	61.55	61.29	60.75	59.57
PL	22.61	37.05	37.20	37.89	39.71
PI	39.71	24.50	24.09	22.86	19.86

Note: LL = Liquid Limit, PL = Plastic Limit

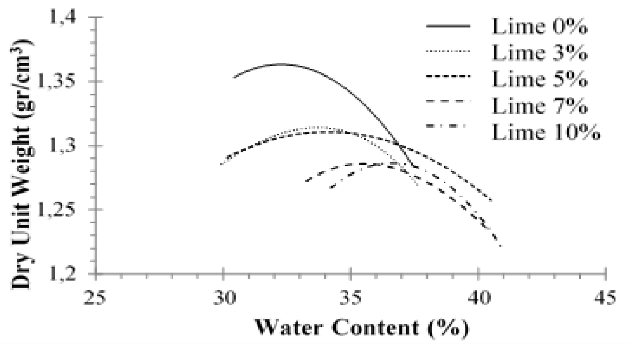
Table 4 shows the plastic limit values for the original soils 1 and 2 are 32.06% and 22.61% while those with 10% lime are 46.85% and 39.71%. Moreover, the original soil plasticity index values 1 and 2 are 41.37% and 39.71% while the value after 10% limestone was added is 22.08 and 19.86% respectively. Figure 1 shows the plasticity index decreases due to the addition of stabilizers (Muntohar, et al, 2013; Nugroho, 2012; Nugroho et al, 2020; Wardani, 2008) and this indicates the results of the Atterberg limit test.

A correlation was found between the optimum moisture content and the maximum dry weight using the Proctor Standard compaction test method as shown in Figure 2.

The results showed the maximum dry weight values of original soils 1 and 2 are 13.37 kN/m^3 and 14.26 kN/m^3 while the addition of 10% lime produced 12.61 kN/m^3 and 13.53 kN/m^3 respectively. Moreover, the optimum soil water content for 1 and 2 is 32.3% and 22.8% while the soil plasticity index value with the addition of 10% limestone is 36.6% and 30% respectively. This means the maximum dry weight decreased while the optimum moisture content increased.



a) Sample 1



b) Sample 2

Figure 2. Effect of lime addition on dry unit weight for soil samples 1 and 2

4.2 Influence of Lime on Unconfined Compressive Strength at Several Conditions

The test found the correlation between the free compressive strength (*qu*) of the soil and the variation of the mixed stabilizer. This was determined using the Unconfined Compression Test method at several conditions of 0 and 28 curing days for unsoaked samples as well as 0 and 28 curing days for soaked samples.

4.2.1 Influence of Lime on Unconfined Compressive Strength for Unsoaked Samples

The UCS results in Figure 3 showed the compressive strength value increased over 28 days. This was observed to be due to the pozzolanic reaction between clay and lime which makes the soil structure to become tougher, more stable, and also causes the potential for shrinkage to decrease. The effective lime variation used for the UCS without curing at 0 days was 5% due to the addition of lime which makes the soil become too stiff and also break easily.

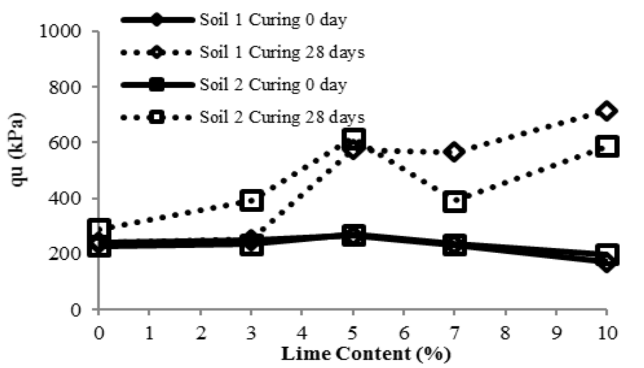
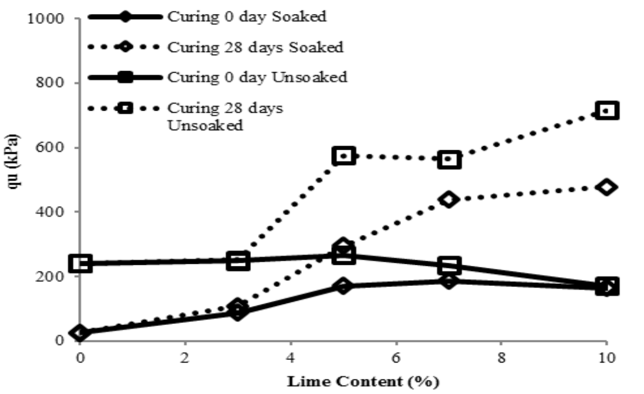


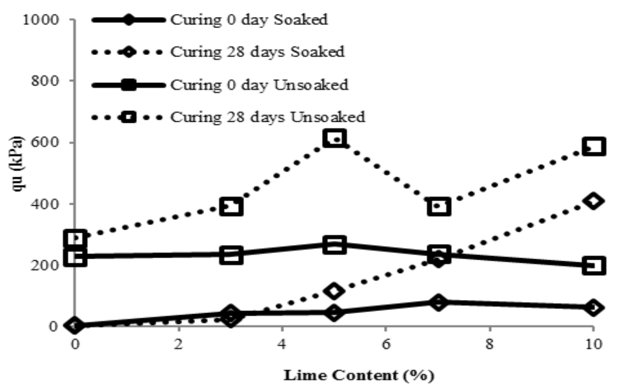
Figure 3. Effect of lime addition on UCS of unsoaked samples

4.2.2 Influence of Lime on Unconfined Compressive Strength for Soaked Samples

The UCS results in Figure 4 showed a decrease in the UCS value of the soaked soils due to damage caused by water on the soil structure which makes it soft.



a) Sample 1



b) Sample 2

Figure 4. Effect of lime addition on the UCS of soaked soil samples

Figure 4 shows the drying conditions of the soil samples 1 and 2 decreased by 33% and 30% respectively after soaking for 28 days.

5 CONCLUSION

The Atterberg test showed a reduction in the plasticity by 46-50%, standard proctor test indicated an increase in the optimum moisture content and a decrease in the maximum dry weight while the UCS test reported an increment after 28 curing days due to long-term pozzolanic reactions between clay and lime.

DISCLAIMER

The authors declare no conflict of interest.

AVAILABILITY OF DATA AND MATERIALS

All data are available from the author.

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