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The Performance of $Ca(OH)_2$ to Reduce the Plasticity Index and Increase the Shear Strength Parameter for Expansive Soil

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ABSTRACT The design on expansive soils can easily change in volume due to the influence of water content. This makes it necessary to consider soil improvement methods in the planning process to maintain the variation in the water content. One of these methods includes chemical stabilization, which is carried out by adding materials such as cement or lime. In expansive soils, stabilization efforts aim to reduce the plasticity index and increase the shear strength parameters. Therefore, this study focused on the addition of slaked lime ($Ca(OH)_2$) to expansive soil in Lakarsantri, Surabaya. The stabilizing materials used contain calcium to form pozzolan in the clay and increase the bearing capacity parameter, which is variation in shear strength. The soil was taken at 2 points A and B with a different moisture content of 48.57% and 35.12%, as well as a high plasticity index value > 50% using a percentage ($Ca(OH)_2$) of 6%-24% at a certain curing time. Based on the results, the plasticity index in the soil changed from very high to moderate with an optimum percentage value of 6% at 30 days of curing time. The optimum value of soil shear strength is ($Ca(OH)_2$) 6% at 30 days of age in Soil A, the cohesion value is 0.02 kg/cm^2, and an internal shear angle of 36°. In Soil B, the optimum shear strength obtained (Ca(OH)2) was 6% at the age of 10 days with a cohesion value of 0.14 kg/cm^2 and an internal shear angle of 23.80°. Therefore, the results of this study show that the parameter of shear strength of the soil from the cohesion value showed that the cohesion value decreased with the addition of Ca(OH)2, while the internal shear angle increased.

KEYWORDS Soil Expansive; Soil Stabilization; $Ca(OH)_2$; Plasticity Indeks; Shear Strength.

1 INTRODUCTION

The expansive soil foundation subgrade significantly influences engineering infrastructure such as planning, design, and construction. Therefore, it needs to be considered when used as the subgrade of construction due to the potential for swelling and shrinkage (Sharma and Sivapullaiah, 2016; Mishra *et al.,* 2008; Yilmaz and Civelekoglu, 2009; Arumairaj and Sivajothi, 2012). Previous studies have shown that a variation in soil water content and dry density affects the swelling behavior of soil. It was also discovered that certain factors affect the swelling potential in soils, these include the clay fraction (F = % finer than 0.002 mm in soil diameter) and the mineralogy of Montmorillonite clays. As the clay fraction increases, the swelling potential rises, thereby influencing soil activity (A). Subsequently, the plasticity index (PI) of the soil affects the swelling potency based on the $A = {}^{PI}/_{F}$ formulation. This shows that the greater the plasticity index, the higher the degree of swelling in soils. The increase in soil activity (A) also improves the swelling behavior, while Arora (1998) observed that the smaller the particle size, the higher the surface activity. This indicated that an increase in the concentration of the surrounding medium will cause a decrease in swelling potential.

Swelling occurs in some soil due to the reduction of stress, which can hinder roadways and structures (Peck *et al.,* 1980). It also causes volume changes, causing extensive damage to civil engineering infrastructures. The swelling behavior of soil contributes to the damage of lightweight structures, shallow foundations, highways, roads, airport pavements, and pipelines. In expansive soils, apart from the potential for shrinkage, the value of shear strength is also low. Therefore, there is a need to reconsider the clay soil expansion technique (Tang *et al.*, 2008; Viswanadham *et al.*, 2009; Liu *et al.*, 2018; Pan *et al.,* 2020). Many soil stabilization techniques using additives materials have been carried out to reduce swelling behavior (Fattah *et al.,* 2010; Abdulaziz *et al.*, 2013; Radhakrishnan *et al.,* 2014).

Soil stabilization is a method of mixing two or more different soils with another geo-material or chemicals that influence its geotechnical properties. It is generally carried out to enhance soil strength and bearing capacity. Meanwhile, soil stabilization is classified into two groups, which include a) mechanical stabilization where the grading is changed by mixing it with other soil types of different grades to achieve a compacted soil mass, and b) chemical stabilization, which is associated with the modification of soil properties by the addition of chemically active materials. In this process, it is important to understand the material properties involved during and after the mixture to determine the material's performance after stabilization.

Lime stabilization of swelling soils has been widely used to improve the physical and mechanical properties of soil (Basma and Al-Sharif, 1994; Fahoum *et al.*, 1996). This method was used as a modified subgrade under the building and road construction. Based on a recent study, the addition of lime is a suitable technique for the stabilization of fine-grained soils. According to Jalal *et al.* (2020), all materials with the basic calcium content are used as stabilizers on soft soils to support the occurrence of pozzolanic reactions that improve soil properties. It was also discovered that lime can be used in different forms, namely hydrated high-calcium and monohydrated dolomitic lime, as well as calcitic and dolomitic quicklime. The calcium in the lime exchanges with the adsorbed cations of the clay mineral. This causes the clay to flocculate, thereby reducing the PI and making it becomes more workable and mixable.

According to Patel (2019), the swelling potential of clay decreases with the addition of lime. Moreover, the absorption of water and the generation of heat during the hydration of quick lime also makes the soil becomes more rigid. This is because lime increases the pH value of soil pore water, releasing silica from the clay mineral. The released silica reacts with the calcium in lime to produce cement, which strengthens the soil with proper curing of the mix. Lime stabilization is particularly used in road projects to modify the properties of subgrade soils, sub-base, and base materials. This method improves material resistance to fracture, fatigue, and permanent deformation. Meanwhile, lime is often used in combination with other additives such as cement and bitumen to compensate for the deficiency of each other or increase the effectiveness of the stabilization process. One type of lime material that is used as a soil stabilization agent is slaked lime, which contains calcium oxide.

Calcium oxide ($Ca(OH)_2$) in slake lime binds soil particles when reacted with H_2O. According to Munirwan (2017) slake lime added to Glee Guenteng clay reduced the plasticity index and soil development. Jullis *et al.*, (2018) conducted a study on the addition of extinguished lime for the value of the plasticity index and direct shear strength on Meunasah clay and obtained the optimum results of 3% and 6%.

Previous studies have shown that expansive clay is almost widely distributed in all locations in West Surabaya. Elena *et al.*, (2020) discovered that the values of LL, PL, PI, the percentage of grains above No. 200 sieve of the soil in the area, and development were included in the high and very high categories. Therefore, this study aims to determine the reaction of extinguished lime to changes in the value of shear strength in expansive clay soils in the Lakarsantri area, West Surabaya. The percentage of the mixture using the variation was determined by curing. Furthermore, the percentage of the mixture of stabilizing agents and variations in curing time were considered.

2 METHDOS

2.1 Soils

The original soil sample was obtained from Jl. Made, Lakarsantri, Surabaya at two points with a distance of ± 50 m from A to B. The sample was collected using 2 methods, namely the disturbed and undisturbed at a depth of 1 m after digging the soil from the surface ± 1 m. The undisturbed sample was obtained using a Selby tube sample point and was used for physical characteristics analysis.

2.2 $Ca(OH)_2$

$Ca(OH)_2$ also known as hydrated lime reacts with water and is a fine grain because it easily absorbs water (Ramaneta, 2020). The lime used in this study was obtained from the Perak area, Surabaya and before mixing with clay, an XRF test was used to obtain a chemical compound as shown in Table 1.

Table 1. XRF Results on $Ca(OH)_2$

Chemical Compound	Percentage (%)
CaO	99.22
SiO	0
Fe_2O_3	0.36
MnO	0.11
CuO	0.03
Eu_2O_3	0.1
Lu_2O_3	0.15

The MnO, Lu_2O_3, Eu_2O_3, and CuO compounds contained in extinguished lime are micronutrients with relatively low percentages. Since they are unlikely to affect the pozzolanic reaction in the mixture of expansive clay soils, he extinguished lime can be used as a stabilizing agent.

2.3 Sample Preparation and Testing

Before mixing soil with $Ca(OH)_2$, a sieve analysis test was carried out on sieve No. 40 to obtain a smooth $Ca(OH)_2$ texture. The sample mixed with the original soil was taken using the disturbed method and the maximum dry weight was determined to ascertain the percentage weight of lime to be used. For example, the lime percentage of 6% at maximum dryness was obtained at 200 gr/cm. Therefore, the percentage weight value of lime at 200 gr/cm^3 was determined using 200 gr/cm^3 x 6% = 12 gr/cm^3. Subsequently, mixing was carried out immediately and stirred evenly as shown in Figure 1.

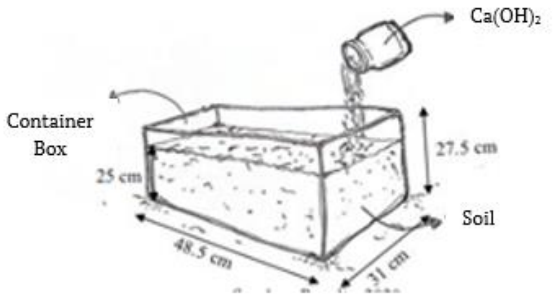

Figure 1. Mixing Process soil – $Ca(OH)_2$ laboratory scale

The percentages of lime for stabilization were 6%, 12%, 18%, and 24% with a curing time of 10, 20, and 30 days, respectively. Based on curing time, soil characteristics were tested on the parameters of the plasticity index and shear strength. The shear strength test was conducted using the direct shear test on all initial and soil stabilization percentages. Furthermore, the XRF test was carried out on the stabilizing material, specifically lime on soils that had optimum results from changes in shear strength and plasticity index values. This test was conducted at the Laboratory of Minerals and Advanced Materials, University of Malang.

3 RESULTS

3.1 Initial soil condition

The initial soil conditions were tested at the Soil Mechanics Laboratory of ITATS and CV. Rubikon Surabaya. The laboratory soil investigations involved volumetric gravimetry test, sieve analysis, hydrometer analysis, Atterberg limit, and direct shear test. Tables 2 through 5 show the results for the Initial soil condition, where the percentages of clay in both soil conditions were above 50%. Based on the Atterberg limit test, both locations had a high plasticity index value. The clay mineral montmorillonite was discovered at Gs values of 2.71 and 2.67, which were based on Das (1995). The direct shear value results showed that both initial soils had a low angle shear friction and strength value < 12 kPa, which indicates very soft soil (Weasley, 2010).

Table 2. Grain sieve and hydrometer results of the initial soil condition

Description		Soil A	Soil B
% Gravel		0	0
% Sand	coarse	0	0
	medium	0.88	0.9
	fines	2.32	2.3
% Silt		39	42
% Clay		58	55

Table 3. Soil properties initial condition

Description	Soil A	Soil B
γt (gr/cm^3)	1.7	1.73
Wc (%)	50.04	35.12
Gs	2.71	2.67

Table 4. Shear strength parameter initial soil condition

Description	Soil A		Soil B	
	c (kg/cm^2)	ϕ (°)	c (kg/cm^2)	ϕ (°)
Initial Condition	0.38	19	0.225	21.35

Table 5. Atterberg limit test initial soil condition

Description	Soil A	Soil B
LL %	79.50	74.00
PL %	23.47	13.27
SL %	13.90	13.20
IP %	56.03	60.73

3.2 Effect of $Ca(OH)_2$ Percentage and Curing Time on Plasticity Index

The plasticity index value decreased with the addition of $Ca(OH)_2$ percentage and curing time. Although the value for the two initial conditions was the same, the decreasing behavior plasticity index that occurred was good at a mixture of 6% lime with 30 days of curing. When lime was 24%, Soil A had a plasticity index value that increased during the curing time from the 20th to the 30th day. These results are similar to the addition of 6% on the 30th day of curing time. Meanwhile, in Soil B, the tendency for changes in the IP value was the same as the percentages of 18% and 24% on the 30th day of curing time. This condition also obtained similar behavior in Soil A, where the plasticity index in soil stabilization was similar to the 6% curing period on the 30th day. The final result for both soil stabilization changed from high to medium plasticity. Figures 2 and 3 show the alteration process between soil condition and stabilization.

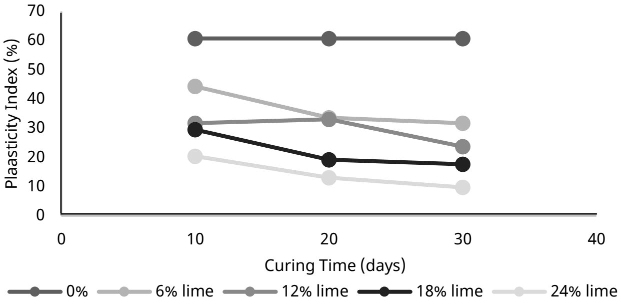

Figure 2. Effect on lime percentage and curing time on Soil A

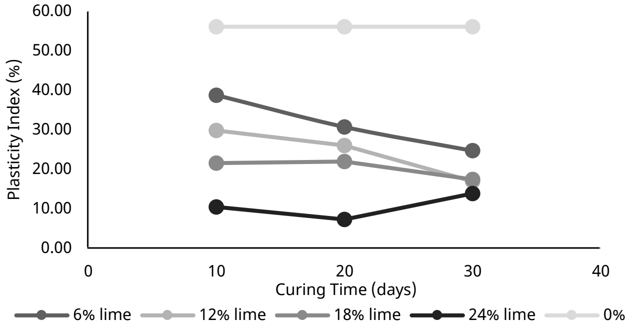

Figure 3. Effect on lime percentage and curing time on Soil B

3.3 Effect of Lime percentage and curing time on Shear Strength Parameter

The next parameter that was observed and analyzed in soil stabilization was the change in shear strength. The changes in shear strength are observed in the value of cohesion and internal shear angle in each of the soils stated below.

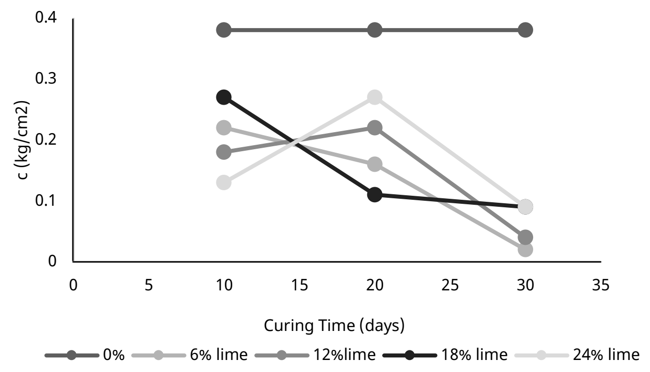

Figure 4. Effect of lime percentage and curing time on cohesion in Soil A

Figure 4 showed the change in cohesion value in Soil A, where the addition of lime to expansion soil decreased the cohesion value significantly. When the lime percentage was added, there was a decrease of 6% and 8% from the 10th to the 20th days, respectively. Furthermore, the addition of 12% and 24% lime tends to change the cohesion values to almost the same. The cohesion value increased from the curing time of the 10th to the 20th and decreased on the 30th day, with optimum results observed on the 30th day. When all the lime percentages were administered, the maximum decrease occurred in 6% lime on the 30th day. The cohesion value before stabilization was 0.38 kg/cm^2, which was optimum at a value of 0.02 kg/cm^2.

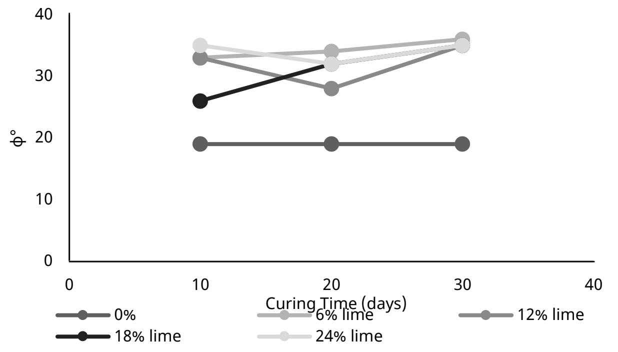

Figure 5. Effect of lime percentage and curing time on the internal angle of friction in Soil A

The shear strength parameter was determined by the magnitude of the change in the shear angle in the soil. When the soil was mixed with a chemical compound, a pozzolanic reaction occurred and in the initial soil condition showed more solid bonded soil grains.

In Soil A, the behavioral changes in the internal shear angle were optimal at 18% lime after stabilization The percentage of lime was 6%, 12%, and 24%. The value of the internal shear angle also increased from the 20th to the 30th day of curing. The addition of 18% lime showed the best results, as the internal shear angle increased from the 10th to the 20th day of curing. However, from the 20th to the 30th day, the change in the internal shear angle was almost constant. Therefore, the optimum results were obtained at 6% lime on the 30th day of curing, with a value of 36° which increased twice compared to the initial soil condition. This value was appropriate with cohesion after soil stabilization and the optimum result was obtained on the 30th day of curing.

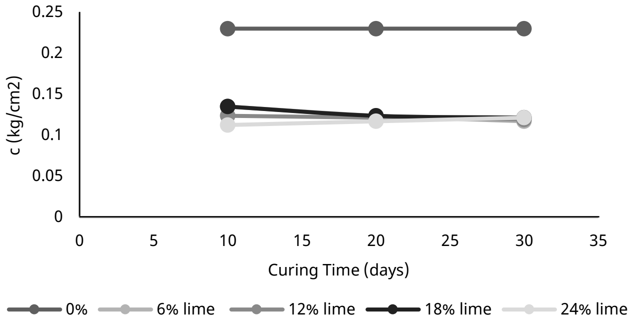

Figure 6. Effect of lime percentage and curing time on cohesion in Soil B

In Soil B, the change in cohesion for each percentage of lime added was small from the 20th to the 30th day of curing. The cohesion value after stabilization was the smallest compared to other percentages with the addition of 24% lime on the 10th day This value tends to be constant at 0.12 kg/cm^2 with a 45% decrease when compared to the initial conditions This was different from Soil A, where the variation in cohesion after mixing changed almost 95%. This showed a better chemical reaction in Soil A due to the water content, which was higher compared to Soil B. From the analysis of the cohesion value, it was concluded that on the 30th day of curing, the cohesion value was at least 0.12 kg/cm^2. However, the results were not significantly different compared to the 10th day of curing with the addition of 6% lime. The value obtained from the change in the cohesion of the initial conditions was 0.23 kg/cm^2 to 0.14 kg/cm^2.

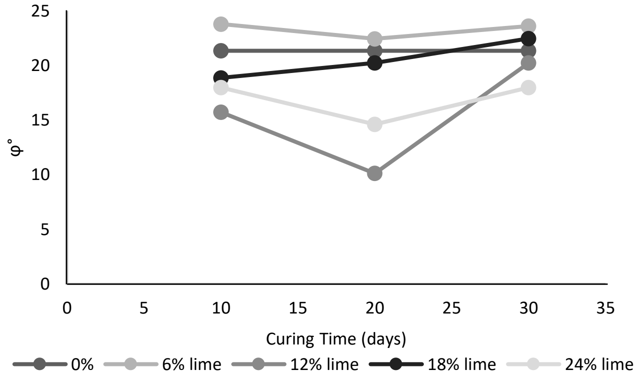

Figure 7. Effect of lime percentage and curing time on internal angle friction in Soil B

Based on stabilized clay B, it was observed that the value of the shear angle of the soil with the addition of 12% lime had the smallest value, which is similar to 24% lime. The optimum change was observed from day 10 to 20, where the value of the internal shear angle decreased and later increased on day 30. At 18% lime, the shear angle value in the soil was closest to the initial condition before stabilization. On the 30th day, the final value of the internal shear angle increased slightly compared to the initial condition, which was 22.47°. Furthermore, the percentage of 6% lime in Soil B showed the best result on the 10th day of curing, which was 23.80°, an increase of 11% from the initial condition of the soil. From the 10th to the 20th day, the value of the shear angle decreased. Meanwhile, the shear angle increased by only 5% from the 20th to the 30th day, which is supported by the small change in cohesion value.

4 DISCUSSION

Based on the two expansive soils in the original conditions used, it was discovered that the water content of Soil A is higher than B. Horpibulsuk *et al.* (2010)conducted a qualitative and quantitative analysis of the microstructure of silty clay soils using a scanning electron microscope. The results showed that water content is one of the parameters that affect soil conditions after stabilization in addition to curing time and cement content. It was also discovered that cement stabilization improves soil structure by increasing cementation bonds between clusters and reducing pore spaces. Meanwhile, when the cement content increased for certain water content in this study, the 3 zones observed were active, inert, and deterioration. The active zone is the most effective for stabilization, where the cement product increases with content and fills the pore space. An effective mixing state was also achieved when the moisture content was 1.2 times the optimum value. Based on the value of the activity number as shown in Table 6, soil B has a higher value, while the initial condition has a normal activity level for both soils

Table 6. Activity level for soil initial condition

Description	Soil A	Soil B
IP (%)	56.03	60.73
Clay (%)	58	55
A	0.97	1.10

The application of the stabilization method on the expansive soil needs to be re-observed on the changes to the curing time in Soil A and B. This is because the results obtained are not visible on variation in shear strength parameters. A previous study by Jalal *et al.* (2020) showed that the effect of microstructure, hydration rate and the reaction of pozzolans in the polymerization and cementation processes play a major role in the duration and conditions of required soil strengthening. This is closely related to the curing time of the soil-stabilized material, which was also obtained in Al-Mukhtar *et al.,* (2012). The study revealed that a small amount of "calcium hydrate" which was newly formed due to the pozzolanic reaction was not always detected by all the techniques because measurements were made in a short time for preservation. Therefore, a combination of macro and microscopic techniques is recommended to analyze the lime-clay reaction and explain the improvement of geotechnical properties.

The condition of the change in the value of the shear angle in the soil needs to be re-observed because several studies obtained slightly different results. Horpibulsuk *et al.* (2010) stated that the strength of the soil was the greatest since the amount of cement product was the highest. In a short stabilization period, the volume of large pores >0.1 ml increases due to the inclusion of coarser particles (un-hydrated cement particles), while the volume of small pores <0.1 ml decreases due to the compaction of gel cement (hydrated cement). Since large pores are filled with cement products, the small pore volume increases, and the total volume decreases, leading to the development of strength over time.

Table 7. XRF result for Soil A with 6% and 30 days curing time

Compound	%
SiO_2	10
Al_2O_3	3.1
CaO	65.3
Fe_2O_3	16.5

The chemical stabilization method requires water for the pozzolanic reaction to occur between the soil and chemicals. This method is carried out using the the results of XRF test of mixed soils. In this study, one optimum sample was used, namely soil sample A with a percentage of 6% and a curing time of 30 days. Based on Table 7, the results of XRF analysis on expansive clays before yielded 55.7% silica tetrahedra and 15.5% aluminum octahedra. After mixing, the lime is extinguished at an optimum yield of 6% with a curing time of 30 days to provide a pozzolanic reaction and reduce the silica contained in the expansive clay.

5 CONCLUSION

Based on the results, the following conclusions are obtained. From the results of the initial soil conditions taken at two locations, the percentage clay content was higher in Soil A than B, namely 58% and 55%, respectively. The plasticity index values for initial conditions at the 2 points were 56.03% and 60.73%. The Gs values in both soils A and B indicate the content of montmorillonite. Moreover, the determination of the optimum percentages of Soils A and B were observed from changes in the value of the plasticity index and shear strength. The shear strength parameter was determined using cohesion value and the shear angle. From the stabilization results, the plasticity value decreased to a medium level. The optimum percentage obtained at the value of the soil plasticity index at points A and B was 6% on the 30th day of curing. In Soil A, the yield after stabilization was 24.64%, while in Soil B, the plasticity index value was 31.68%. The parameter of shear strength of the soil from the cohesion value showed that the cohesion value decreased with the addition of extinguished $Ca(OH)_2$, while the internal shear angle increased. This is influenced by the presence of a pozzolanic reaction which is affected by the percentage of clay, water content, and ripening age. The conditions of Soil A and B had different curing times and the optimum percentage was 6% $Ca(OH)_2$.

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