

Changes in the Physical and Mechanical Properties of Clay Soil Due to Stabilization with Lime

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Abstract: Clay soil stabilization is a crucial process to enhance the soil's bearing capacity and stability, making it more suitable for construction purposes. Stabilizing clay soils improves their mechanical properties, reduces swelling, and increases their load-bearing capacity, which is essential for the foundation of various structures. This study aims to investigate the effect of lime (CaO) addition and curing time on the physical properties of clay soil, particularly focusing on unconfined compressive strength (qu) and overall soil stability. The experimental methodology involved applying different percentages of lime content (ranging from 3% to 7%) and varying curing times (7, 14, and 28 days). The soil samples were tested for their unconfined compressive strength after each combination of lime content and curing duration. The results indicated that the addition of 5% lime (CaO) and curing for 14 days led to a significant improvement in the unconfined compressive strength by 153.3%, compared to the untreated clay soil. Furthermore, increasing the curing time beyond 14 days did not show substantial improvements in strength, suggesting that 14 days is the optimal curing period for this combination. The study also highlighted that the lime treatment not only enhanced the mechanical properties but also reduced the plasticity of the clay, making it more stable and easier to handle during construction. Based on these findings, it can be concluded that the appropriate combination of lime content and curing time plays a significant role in improving the stability of clay soils. This research provides valuable insights into optimizing soil stabilization techniques, offering an effective solution for enhancing soil properties for engineering applications.

Keywords: Lime (CaO); Soil Mechanical; Soil Physical; Soil Stabilization

1. Introduction

The rapid development of human civilization, particularly in the transportation sector, has placed significant emphasis on road infrastructure, which is essential for facilitating the efficient movement of people and goods (Aqel et al., 2024). Stable and high-quality road conditions rely heavily on the soil beneath the pavement, as inadequate soil properties, such as low bearing capacity, can lead to issues such as settlement and structural failure (Hou et al., 2025). In regions like Indonesia, where clay soils are prevalent, these soils often pose challenges due to their high plasticity and susceptibility to volume changes caused by water content fluctuations (Tavala, 2025). Recent studies have shown that the addition of lime (CaO) and other stabilizers significantly improves the mechanical properties of clay soils, such as compressive strength, making them more suitable for construction purposes (Almuaythir et al., 2025). Additionally, various stabilization techniques, including the use of industrial by-products like silica fume and fly ash, have proven effective in enhancing soil stability for infrastructure projects (Almeida et al., 2024; Tavala et al., 2025). Moreover, sustainable soil stabilization practices, such as using bamboo charcoal and quarry dust, have emerged as

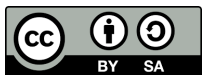
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environmentally friendly alternatives, providing effective solutions to soil instability (Agate et al., 2024). These advancements underscore the importance of soil stabilization in ensuring the durability and safety of roads, particularly in areas with expansive and low-bearing soils.

Therefore, efforts are needed to improve clay soil to meet technical requirements for construction. One common method for improving soil quality is soil stabilization, which involves adding certain materials that can improve the soil's mechanical and physical properties.

One of the materials frequently used in soil stabilization is lime (CaO). Lime reacts with soil and water, thus changing the soil's properties to become more stable. The chemical reaction between lime and clay minerals produces calcium silicate, which strengthens the soil's structure and reduces its expansive properties.

Thus, soil stabilized with lime will have better bearing capacity and be more resistant to changes in water content. Soil stabilization with lime has been widely applied in various road construction and other infrastructure projects.

In this study, the authors will use activated lime (CaO) as a stabilizing agent for expansive clay soil originating from the Kayu Agung area. Unlike previous studies, the lime content variations used in this study are 1%, 3%, 5%, 7%, and 10%, with curing times of 0, 3, 7, 11, and 13 days. It is hoped that this research will produce more effective findings in improving clay soil stability, thus enabling its application in construction projects requiring soil improvement with similar characteristics.

2. Preliminaries or Related Work or Literature Review

2.1 Materials and tools

In this research, various tools were used to support the testing of the physical and mechanical properties of the soil. The equipment used included a set of sieves, which separate soil particles or other materials into specific sizes, commonly used in testing the physical and mechanical properties of soil. In addition, spoons and mixing bowls were used to transfer samples to the required containers and to assist in mixing the soil with water. Plastic containers or bags were also used, particularly as measuring tools in mechanical soil tests such as compaction and curing.

For the compaction process, a pestle and mold are used to shape the soil sample according to testing standards. A crucible is used for soil moisture testing, while a vernier caliper is used to precisely measure the dimensions of a cylinder for soil mechanical properties testing. A balance plays a crucial role in weighing soil samples with high accuracy, while a drying oven is used to remove moisture from the sample to obtain an accurate dry mass.

In the Atterberg limit test, a set of tools consisting of a Casagrande apparatus, a cutting knife, and a leveler is used to measure the soil's plasticity. The soil's specific gravity is measured using a pycnometer, a specially designed bottle. Additionally, a dial gauge is used as

a measuring tool in testing the mechanical properties of the soil, for example in immersion tests.

The materials used in this study were carefully selected and tested in accordance with applicable requirements to ensure scientifically sound results. The primary material used was clay soil sourced from the Kayu Agung area. This clay has high shrinkage and expansion properties, making it suitable for use as a road subgrade research material. All testing was conducted at the Soil Mechanics Laboratory at Muhammadiyah University of Palembang.

In addition to soil, activated lime (CaO) obtained from Toko Putra Primajaya Palembang was also used as a soil stabilizer during testing. The water used in the study came from the Palembang Regional Water Company (PDAM) to ensure its quality and consistency during the mixing and testing process.

2.2 Method

This research was conducted using an experimental method in the laboratory, which aims to analyze the effect of the addition of activated lime (CaO) and variations in curing time on the stability of clay soil. The research activity began with the stage of sampling clay soil from the Kayu Agung area, which is characteristically classified as expansive soil with a high level of shrinkage and swelling. Sampling was carried out by observing technical procedures to ensure that the original properties of the soil were maintained until the laboratory testing stage. The next stage was the preparation of research materials, which included initial testing to determine the physical and mechanical characteristics of the original soil. This testing was carried out to obtain baseline data for comparison with the results after the stabilization treatment. The stabilization process was carried out by mixing dry clay soil with activated lime (CaO) at five varying levels, namely 1%, 3%, 5%, 7%, and 10% of the dry weight of the soil.

After the mixing process, a curing stage is carried out with five time variations: 0, 3, 7, 11, and 13 days. The curing stage aims to allow time for the reaction between the soil minerals and the chemical elements in the lime, thus initiating a pozzolanic process that can increase the strength, density, and stability of the soil.

Following the curing stage, the soil samples underwent a series of physical and mechanical tests to evaluate the effectiveness of the treatment. The tests were conducted following established procedures and standards, ensuring scientifically sound results.

2.3 Location and Time

This research was conducted at the Soil Mechanics Laboratory of Muhammadiyah University of Palembang in March - April 2023.

3. Proposed Method

3.1. Soil Test Results with Lime Addition

In this study, two types of tests were conducted on soil with the addition of Lime (CaO) with variations of 1%, 3%, 5%, 7% and 10%, namely Compaction Test and Unconfined Compressive Strength Test. The Compaction Test aims to obtain maximum soil density at standard energy, by providing optimum water content. The use of standard proctor testing is to find the maximum density value and optimum water content of a soil sample. The Unconfined Compressive Strength Test aims to measure how much the soil's bearing strength receives the given compressive force until the soil is separated from its grains and also the soil strain due to the pressure. The following are the results of soil tests that have been added with Lime (CaO):

Table 1. Soil Test Results with Lime Addition

| Day | Note | 0% | 1% | 3% | 5% | 7% | 10% |
|---------|---------------------------|----------|----------|----------|----------|----------|----------|
| 0 Days | Average Water Content (%) | 32.67326 | 35.85287 | 28.24435 | 34.43759 | 33.29008 | 31.68129 |
| | Dry Volume Weight | 1.180037 | 1.151406 | 1.233879 | 1.209614 | 1.134503 | 1.158374 |
| | ZAV | 1.468834 | 1.397049 | 1.541944 | 1.401123 | 1.433002 | 1.506159 |
| 3 days | Average Water Content (%) | 33.90436 | 30.0246 | 40.9435 | 33.16515 | 30.24895 | 32.32993 |
| | Dry Volume Weight | 1.222415 | 1.196094 | 1.129616 | 1.238862 | 1.161005 | 1.142901 |
| | ZAV | 1.412862 | 1.491608 | 1.309493 | 1.435535 | 1.496924 | 1.490885 |
| 7 Days | Average Water Content (%) | 29.25057 | 29.75047 | 35.79092 | 33.32814 | 36.74558 | 39.25341 |
| | Dry Volume Weight | 1.230272 | 1.200015 | 1.171609 | 1.237835 | 1.112465 | 1.0901 |
| | ZAV | 1.516911 | 1.505622 | 1.396463 | 1.432796 | 1.397198 | 1.352139 |
| 11 Days | Average Water Content (%) | 33.19134 | 28.64989 | 30.05958 | 27.47573 | 46.57883 | 27.59722 |
| | Dry Volume Weight | 1.134832 | 1.21234 | 1.227206 | 1.305457 | 1.031338 | 1.18079 |
| | ZAV | 1.438268 | 1.537745 | 1.546228 | 1.597602 | 1.202416 | 1.561864 |
| 14 Days | Average Water Content (%) | 32.38855 | 21.41511 | 20.31217 | 20.43087 | 20.34281 | 21.53808 |

| | | | | | | |
|-------------------------|----------|----------|----------|----------|----------|----------|
| Dry Volume Weight | 1.152926 | 1.651078 | 1.682621 | 1.699894 | 1.685735 | 1.675226 |
| ZAV | 1.491466 | 1.707222 | 1.740134 | 1.737158 | 1.74081 | 1.705064 |

Source: Testing 2023

From this table, it can be seen that in general, the average water content varies depending on the lime content and the curing time. At 0 days of curing, the average water content ranged from 28.24% to 35.85%, with the highest value in the 1% lime mixture and the lowest in the 3% lime mixture. As the curing time increased to 14 days, the average water content decreased significantly, especially in mixtures with higher lime content. On the 14th day, the water content ranged from 20.31% to 32.38%, with the largest decrease in the 5% to 10% lime mixture. This decrease in water content indicates that lime plays a role in binding water and improving the soil drying process.

The dry unit weight indicates the maximum density of the soil after compaction. At 0 days of curing, the dry unit weight ranged from 1.13 g/cm³ to 1.23 g/cm³. After 14 days of curing, the dry unit weight value increased significantly, especially in the 1% to 10% lime mixture, with a range of 1.15 g/cm³ to 1.69 g/cm³. This increase in dry unit weight indicates that the reaction between lime and soil improves soil density, increases its bearing capacity, and reduces its porosity.

The ZAV value indicates the maximum theoretical density if the soil is completely compacted without air voids. At 0 days of curing, the ZAV value varied between 1.40 and 1.54 g/cm³, with the highest value in the 3% lime mixture. After 14 days of curing, the ZAV value increased in all mixtures, with a range of 1.49 to 1.74 g/cm³, indicating that lime stabilization resulted in a more optimal density within a certain period.

The longer the curing time, the soil water content tends to decrease, especially at higher lime content. The dry unit weight increases with curing time, indicating increased soil density and stability. The ZAV value also increases, indicating that the lime stabilization process is increasingly effective in increasing the strength and bearing capacity of the soil after curing. A mixture with 5% to 10% lime at 14 days curing showed the best results in increasing dry unit weight and reducing water content, making it the most effective combination for clay soil stabilization.

3.2 The Effect of Adding Lime (CaO) and Curing Time on the Physical Properties of Clay Soil

To find out the effect of adding lime (Cao) of 1%, 3%, 5%, 7% and 10% with a curing time of 0, 3, 7, 11 and 14 days, it can be concluded and presented in the following graphs below:

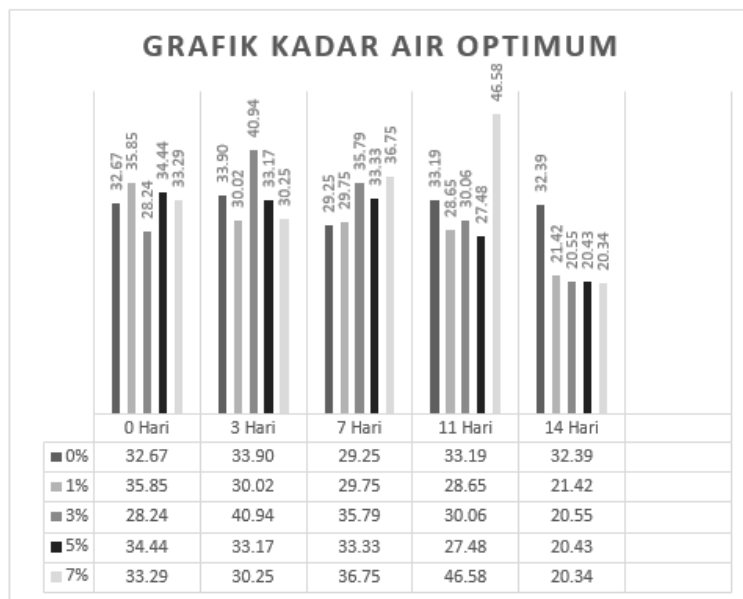


Figure 1. Optimum Water Content Graph

Based on the picture above, it is known that the addition of lime and also the curing time greatly affects the properties of clay soil seen from its Optimum Water Content, it can be seen that the optimum water content value of clay soil gradually decreases with the length of the curing time of 14 days, this is caused by the greater variation in the value of the lime content mixed, the optimum water content value will decrease because the lime binding process reacts with clay minerals in the soil, or with other fine grains, to form bonds between water and insoluble gels from calcium silicate, which bind soil particles which causes the optimum water content value to shrink.

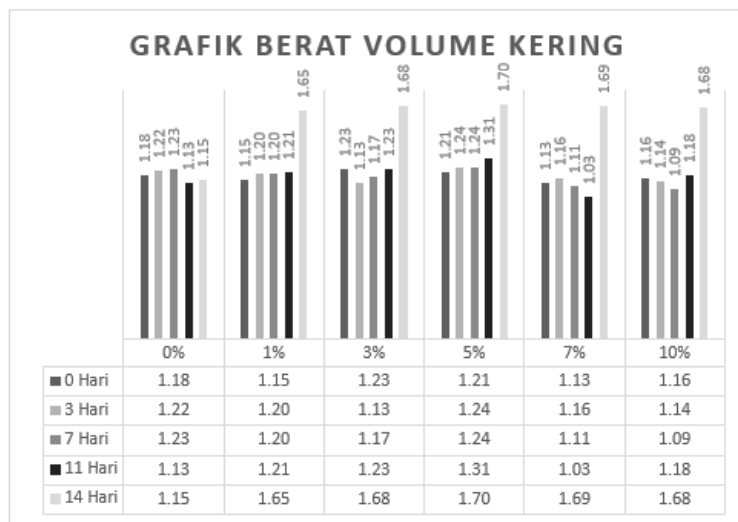


Figure 2. Dry Volume Weight Graph

It can be seen from each variation there is a change in the value of the volume weight. It can be concluded based on the graph above that the greater the variation in the value of the lime content mixed at the longest curing time, the greater the value of the volume weight will be. This is because the binding process of lime reacts with clay minerals in the soil, or with other fine grains (pozzolanic components such as silica hydrous), to form bonds between

water and an insoluble gel of calcium silicate, which binds soil particles which increases the value of the dry unit weight. In the variation of adding 5% lime, the value of the dry unit weight of the soil gradually increases from day to day and then becomes the highest compared to other variations, because the lime content with the right variation makes the process of increasing the value of the dry unit weight of the soil.

3.3 Variations in Lime (CaO) Mixture and Length of Curing Time to Achieve Optimum Value as Clay Soil Stabilizer

To see the magnitude of the variation in the lime (CaO) mixture and the length of the curing time to achieve the optimum value as a clay soil stabilizer, you can see the magnitude of the unconfined compressive strength of the original soil and the soil with a lime additive mixture. The unconfined compressive strength of the soil is presented in the table and graph below:

Table 2. Unconfined Compressive Strength

| Time/Day | Unconfined Compressive Strength | | | | | |
|----------|---------------------------------|---------|---------|---------|---------|---------|
| | Additive | | | | | |
| | 0% | 1% | 3% | 5% | 7% | 10% |
| 0 | 0.23679 | 0.23679 | 0.35285 | 0.54936 | 0.42010 | 0.45242 |
| 3 | 0.99249 | 0.84020 | 0.79716 | 0.71514 | 0.99597 | 0.76642 |
| 7 | 0.35285 | 0.19389 | 0.42010 | 1.08271 | 0.54936 | 0.25395 |
| 11 | 0.42010 | 0.25852 | 0.42320 | 1.09644 | 0.32554 | 0.42010 |
| 14 | 0.45242 | 0.91756 | 0.99249 | 1.14272 | 1.08633 | 0.87280 |

Source: 2023 Testing

In the UCT test, the unconfined compressive strength (qu) of soil with a 5% lime mixture is greater than the original soil without treatment or with treatment. The unconfined compressive strength (qu) of soil with a 5% lime mixture with treatment tends to increase compared to that without treatment. The largest unconfined compressive strength (qu) value with treatment was obtained in soil with a 5% lime (CaO) mixture with a treatment time of 14 days, namely an increase of 153.3% compared to that without treatment with an increase of 45.8%.

4. Results and Discussion

4.1 Conclusion

Based on the research results presented previously, it can be concluded that lime addition and curing time significantly affect the physical properties of clay soil. This is evident from changes in the optimum water content, which results in shrinkage and an increase in the dry unit weight of the clay soil. The results from the tables and graphs indicate that the longer the curing time and the higher the lime content added, the more stable the clay soil becomes and its bearing capacity improves for construction purposes.

Furthermore, this study also showed that the unconfined compressive strength of the soil increased with the addition of lime and curing time. The best results were obtained with

a soil mixture containing 5% lime (CaO) cured for 14 days, with an increase in unconfined compressive strength of 153.3% compared to the untreated soil. This indicates that this combination provides the most optimal effect in increasing soil strength, making it a good alternative in stabilizing expansive clay soil.

Overall, this study confirms that the use of lime as a clay soil stabilizer can significantly improve soil quality. Its effectiveness is evident in improvements in the soil's physical and mechanical characteristics, such as reduced water content, increased dry unit weight, and increased unconfined compressive strength. Therefore, this stabilization method can be applied to various construction projects, particularly in areas with low soil bearing capacity.

4.2 Suggestion

Based on the research results obtained, it is recommended that the clay soil stabilization method using the addition of activated lime (CaO) at a concentration of 5% and a curing time of 14 days can be applied to construction projects, particularly in areas with expansive clay soil conditions. This combination has been proven to provide the most optimal results in increasing soil stability and bearing capacity, making it suitable for use in road subgrade work and building foundations.

To ensure consistency of results between laboratory testing and field application, it is necessary to develop standard operating procedures (SOPs) that govern the mixing process, lime distribution, and curing stages. This ensures that the soil stabilization process in the field can be carried out in a measurable manner and produce quality that meets the desired technical specifications.

Further research is recommended to expand the testing parameters, not just limited to physical properties and unconfined compressive strength, but also to include CBR (California Bearing Ratio) testing, triaxial testing, and durability testing. This will ensure more comprehensive research results and provide a more accurate picture of the performance of stabilized soil under actual field conditions.

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