



Analysis of lime mixture on the characteristics of the physical and mechanical properties of the soft soil

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Abstract

This study focuses on soft silty soil from the Kedung Baruk area in East Surabaya, which has poor geotechnical properties, such as low bearing capacity, high moisture content, and high saturation. This soil is fine-grained with low to medium plasticity, and is highly sensitive to moisture changes, causing volume changes (shrinkage and expansion). These characteristics make it unsuitable as a foundation material, especially in humid, high-rainfall areas like East Surabaya. The research examines the effect of adding calcium carbonate lime on the soil's physical and mechanical properties. Lime, with high CaCO_3 content, was mixed with the soil in varying amounts (0%, 5%, 10%, 15%, 20%). Laboratory tests showed that lime reduced moisture content and plasticity, while increasing density and compressive strength, particularly at 15%. However, at 20%, the density decreased due to non-homogeneous lime aggregates. Chemically, calcium carbonate reacts with soil silica/alumina to form hydrated calcium silicate (CSH) and calcium aluminate (CAH), improving soil particle bonding, structure, strength, and stability. Lime offers a cost-effective and eco-friendly alternative to cement or fly ash for soil stabilization, though its reaction is slower. Thus, calcium carbonate lime effectively improves soft silty soil quality in Kedung Baruk.

Keywords: Lime, Soil Physical Properties, Soil Mechanical Properties, Lime Mixing, Soft Silt Soil

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INTRODUCTION

In the construction industry, particularly in the field of Geotechnical Engineering, soil parameters at the construction site play a crucial role in determining the success of a development project[1]. The soil, as a medium supporting structural loads, must possess stability, bearing capacity, and consistent [2]. However, in many areas of Indonesia, the soil types are not always suitable and ideal for construction projects[3][4]. One common soil type encountered is soft soil, which has fine particles, high moisture content, and physical and mechanical properties that are less favorable for construction[5][6][7].

Approximately 10 percent of Indonesia's total land area, equivalent to approximately 20 million hectares, is dominated by soft soil[8][9]. Official data from the Ministry of Energy and Mineral Resources (ESDM), through the Geological Agency, reveals that this soft soil is widespread, particularly in areas with alluvial deposits such as coastal plains, rivers, swamps, and lakes. These areas include the

eastern Sumatra coast, the Kalimantan coast, southern Papua, and the eastern part of Java, with one of the locations being the Kedung Baruk area in East Surabaya. Therefore, an effective improvement method is needed to enhance the physical and mechanical properties of soft soil, such as bearing capacity, unconfined compressive strength, and stabilization[10][11].

One method to improve poor soil properties is soil stabilization, which involves mixing or adding additives to soil particles with undesirable properties[12]. A widely applied method in the field is soil stabilization through the addition of lime, which is known to reduce the plasticity of soft soil, enhance the bonding between soil particles, and significantly decrease its water absorption capacity[13]. Thus, mixing soft soil with lime becomes a viable solution to enhance the stability of the foundation soil in construction, especially in areas with soils susceptible to damage[4]. However, the challenge in its application is determining the optimal lime dosage to improve soil performance without affecting other factors, such as cost, processing time, and environmental impact[14][15].

Research has explored the use of calcium lime as a stabilizing material for soft silt soil, but there has yet to be an in-depth study on its optimal dosage. Further research on the effect of calcium lime mixing on the physical, mechanical characteristics, and unconfined compressive strength of soft silt soil is needed to stabilize it[16][17].

The aim of this study is to identify the change flow of soil properties due to the addition of calcium lime, understand the chemical reaction mechanisms between calcium lime and soil components, and determine the optimal calcium lime dosage in improving bearing capacity, unconfined compressive strength, and soil density. Practically, this research is expected to provide applicable solutions for stabilizing soft silt soil to enhance the stability of building structures and infrastructure. The findings from this study can serve as a reference for soil improvement techniques in construction projects, particularly in areas with soft silt soil.

METHOD

This study uses an experimental quantitative method by creating test specimens to determine the effect of mixing lime with soft soil on the physical and mechanical properties, as well as the optimum lime content. The study utilizes soft soil samples collected from Kedung Baruk, East Surabaya, East Java. The composition of the soft soil used includes native soil, undisturbed soil, and disturbed soil, as outlined in Table 1.

Table 1. Composition of the mixture used for soft silt soil and calcium lime.

Material	The weight percentage of the test specimen				
soft silt soil	100	95	90	85	80
Calcium lime	0	5	10	15	20

The testing process for soft clay soil begins with sampling from the research site, followed by natural drying, storage in a dry state, and screening using a number 4 sieve to obtain a homogeneous soil fraction. The screened soil is then used in various laboratory tests to identify its physical properties, including natural moisture content, specific gravity, degree of saturation, particle gradation, and

Atterberg limits. In addition, the soil fraction that passes through a 200-mesh sieve is also collected for further analysis. Next, tests were conducted on the mechanical properties of the soil, focusing on two main parameters, namely the compaction test using the Standard Proctor method to determine the relationship between moisture content and maximum dry weight, and the unconfined compressive strength (UCS) test used to determine the soil's ability to withstand axial loads without lateral restraint. Both types of tests aimed to assess changes in the behavior of soft clay soil as a result of mixing stabilization materials, in this case calcite lime, to obtain an overview of the effectiveness of lime in increasing the density and strength of soil as a construction base material.

RESULTS AND DISCUSSION

Research on Baruk Surabaya soft soil and limestone mixtures shows that the behavior of soft soil with potential subsidence can be stabilized with limestone. Changes in moisture content, Atterberg limits, and degree of saturation are intended to provide information about physical and mechanical properties. Visually, the condition of the sample location is commonly identified as soft soil that can cause subsidence and instability in construction. The effects of these factors are discussed as follows.

1. Physical Properties of Soft Clay Soil in Baruk Surabaya

a. Moisture Content

Water content testing is intended to determine the water content of a soil sample, which is the ratio between the weight of water and the weight of dry soil. Laboratory testing of the original soil showed that the water content (w) at the sampling location in the Baruk Surabaya area decreased after the addition of stabilization material with lime. The water content test showed that the addition of lime stabilizing material resulted in a decrease in the water content value.

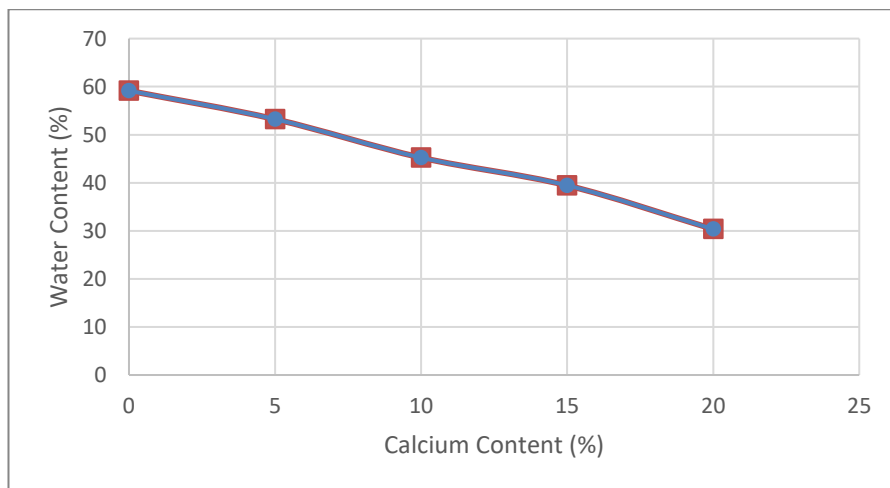


Figure 1 Relationship between lime content and soil moisture content

Figure 1 shows the water content (w) of 100% Soft Lanau soil + 0% lime with a value of 59.14%, while the water content (w) value for Soft Lanau soil and a

mixture of 95% + 5% is 53.23%, Soft Silt soil and a mixture of 90% + 10% lime is 45.23%, Soft Silt soil and a mixture of 85% + 15% lime is 39.45%, and Soft Silt soil and a mixture of 80% + 20% lime is 30.35%. The moisture content test shows that the more lime is mixed in, the lower the moisture content value becomes.

b. Specific Gravity

Based on the results of this study, the specific gravity of a soil sample with particles passing through a No. 4 sieve was determined using a picnometer. Specific gravity is the ratio between the weight of distilled water and the weight of soil particles. From the results of the specific gravity study, the results of mixing Baruk Surabaya soft sandy soil with lime are as follows.

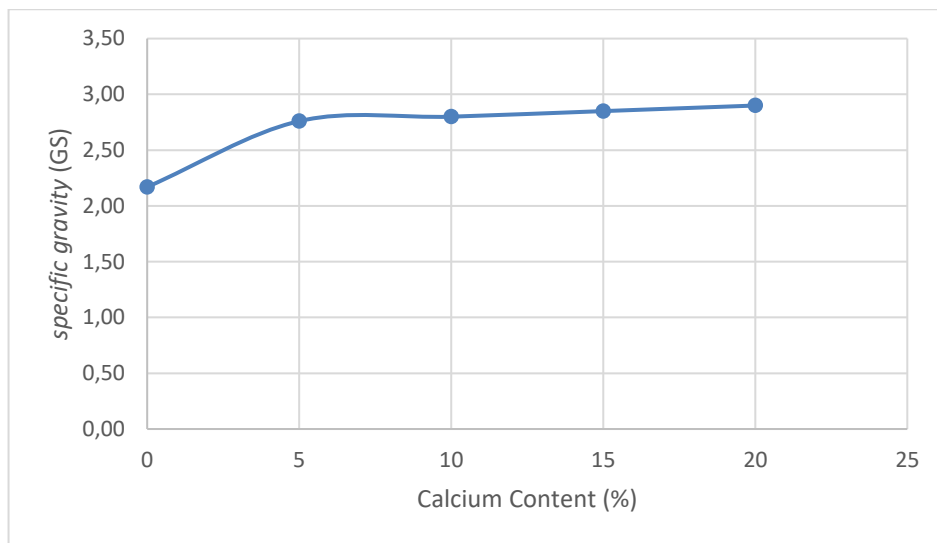


Figure 2 Relationship between Calcium Content with soil specific gravity

Figure 2 shows the results of mixing soft sandy soil with lime. Soft sandy soil 95% stabilized with a 5% lime mixture has a specific gravity value of 2.76%. A 90% stabilization value added to 10% lime results in a specific gravity of 2.80%. an 85% stabilization value increased to 15% limestone resulted in a specific gravity value of 2.85%, and an 80% stabilization value increased to 20% limestone resulted in a specific gravity value of 2.90%. These research results show that the greater the addition of limestone stabilization material, the higher the specific gravity (Gs) value.

c. Atterberg Testing

The Atterberg limit test provides a general overview of the properties of the soil. Soil with a high liquid limit usually has poor technical properties, namely low strength, high compressibility, and difficulty in compaction.

- Liquid Limit

Test results on liquid to determine the water content of soil at the liquid limit. The liquid limit is the water content at which soil changes from a liquid state to a plastic state. Usually, this test is conducted on soil samples with different water contents, and the number of blows is calculated for each water content.

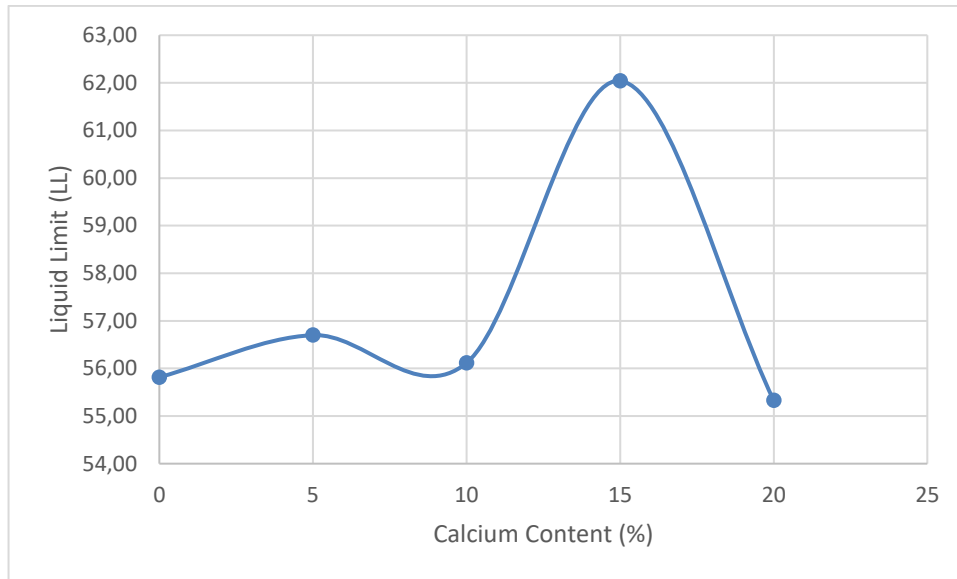


Figure 3 Relationship between lime content and liquid limit of soil

Figure 3 shows that the liquid limit fluctuates with the increase in the percentage of lime. The smallest liquid limit is obtained in native soil at 55.82% and in a mixture of 80% soft clay soil + 20% lime at 55.33%, while the largest liquid limit is obtained in soil mixed with 95% lime + 5% clay at 56.70%. the liquid limit in the 90% + 10% mixture was 56.12%, and the liquid limit in the 85% + 15% mixture was 62.04%. This occurred because the addition of lime caused the Soft Silt soil particles to enlarge, resulting in fluctuations in cohesion.

- Plastic Limit

The plastic limit is used to determine the moisture content of soil at its plastic limit. The plastic limit is the minimum moisture content at which soil remains plastic. This limit is the lowest level of soil plasticity.

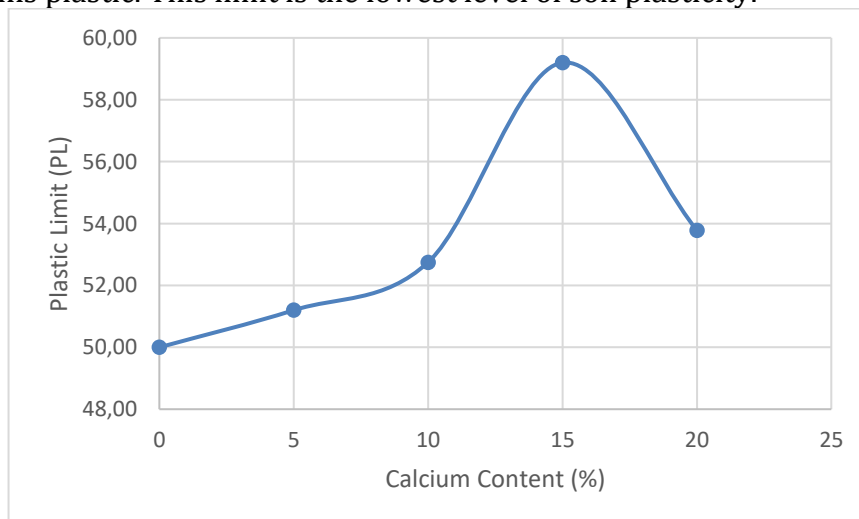


Figure 4 Relationship between lime content and soil plastic limit

Figure 4 shows that the plastic limit increases with increasing percentages of lime and soft clay soil. The plastic limit test results for 100% sand + 0% expansive

clay were 50%. The plastic limit increased after stabilization of 95% soil + 5% lime to 51.2%. The plastic limit increased and was highest after stabilization of 90% soil + 10% lime to 52.75%. followed by the soil mixture of 85% + 15% lime at 59.2%, and the sand mixture of 80% + 20% lime experienced a decrease to 53.78%.

- Plasticity Index

The difference between the liquid limit and the plastic limit is the area where the soil is in a plastic state (plasticity index). From the results of plastic index testing in the laboratory, the following results were obtained. The results of testing the physical properties of the soil mixture show that the water content, liquid limit, plastic limit, plastic index, percentage passing the No. 200 sieve, and index decreased with the addition of calcite lime.

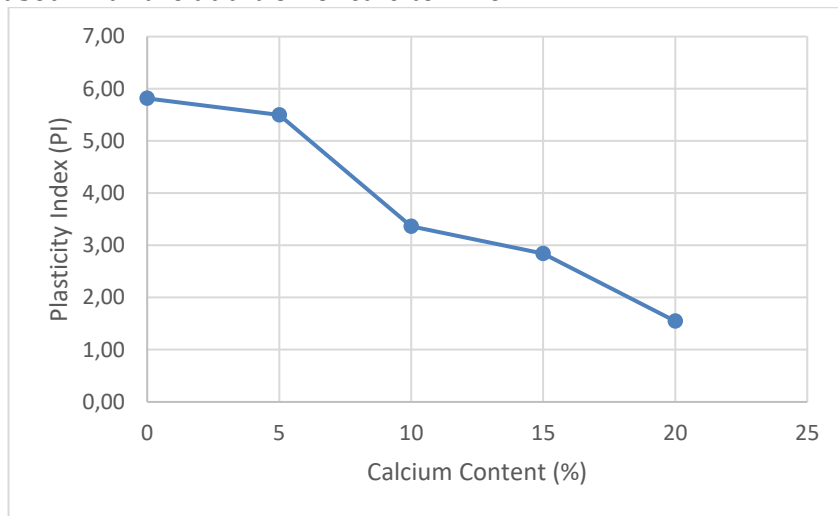


Figure 5. Relationship between lime content and soil plasticity index

Figure 5 shows that the plasticity index result is the difference between the liquid limit (LL) and the plastic limit (PL). The plastic index decreased with the addition of limestone stabilizer, where the mixture of 100% soil + 0% limestone was 5.82%, then stabilized with 95% soil + 5% lime at 5.8%, then mixed again with 90% soil + 10% lime at 3.37%, then stabilized with 85% soil + 15% lime at 2.84%, and a soil mixture of 80% + 20% lime at 1.55%.

2. Mechanical Properties of Soft Lanau Baruk Soil in Surabaya

a. Compaction Analysis (Standard Proctor Test)

The standard compaction test was conducted to determine the maximum dry weight (γ_{dmax}) and optimum moisture content (W_{opt}), where the soil type has one optimum moisture content value to achieve maximum dry bulk density, as shown in Figure 4.2 below.

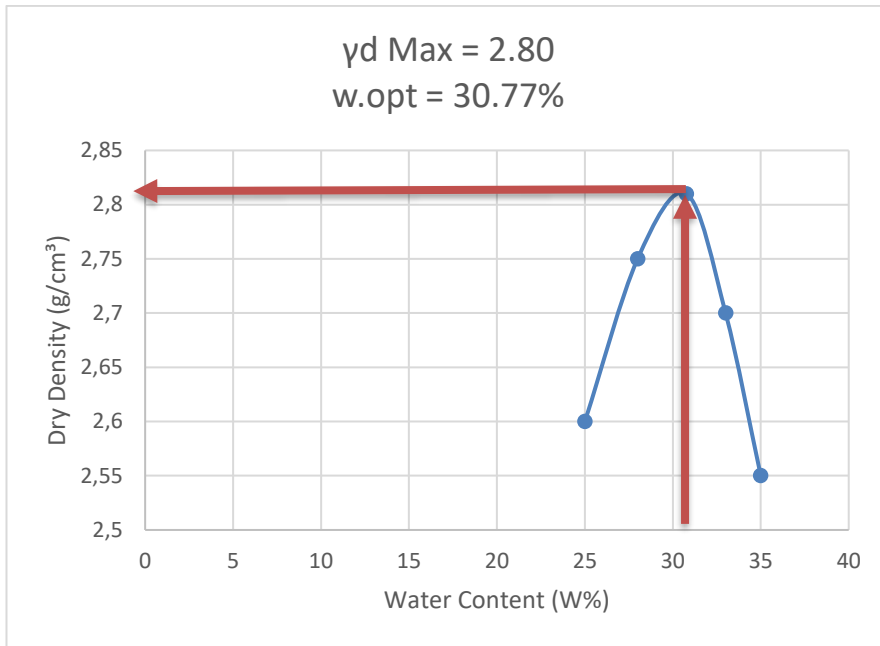


Figure 6 Relationship between moisture content and dry weight of soil

Figure 6 shows the test results for dry weight (γ_d) of Baruk Surabaya soil mixed with lime. The dry weight (γ_d) was 2.80. Adding 5% lime increased the dry weight (γ_d) to 2.81, and adding 10% lime increased the dry weight (γ_d) to 2.85. Adding 15% lime resulted in a dry weight (γ_d) of 2.90, and adding 20% expansive clay reduced the dry weight (γ_d) to 2.45.

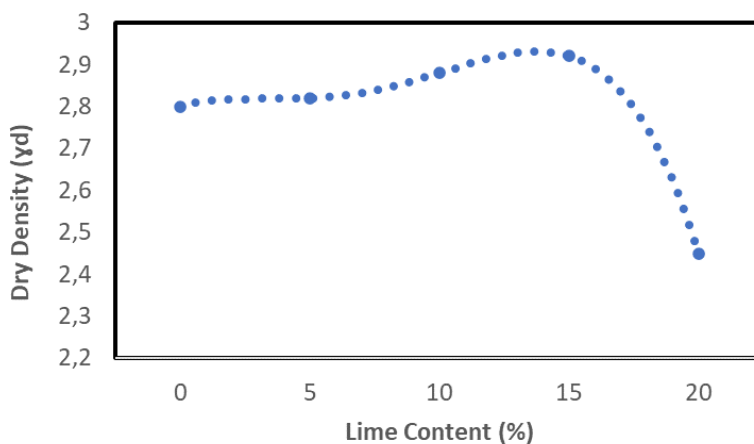


Figure 7 Relationship between caput content and dry weight (γ_d) of mixed soil

Figure 7 shows the relationship between lime content (%) and dry weight of mixed soil (γ_d). In this graph, the horizontal axis (X) represents the lime content of the soil, ranging from 0% to 20%, while the vertical axis (Y) represents the dry weight of the soil (γ_d), measured in kN/m^3 . From the graph, it can be seen that the relationship between lime content and dry weight of soil has a distinctive shape. Initially, when the lime content is still low (around 0% to 5%), the dry weight of soil tends to be stable and does not show significant changes. However, as the lime

content increases, the dry weight of soil begins to increase. The highest peak of dry weight of soil occurs at around 10-15% lime content. After reaching this peak, the graph shows a decrease in dry weight as the calcium content increases beyond 15%. The decrease in dry weight at higher calcium levels can be understood through changes in the physical properties of the soil. Higher calcium levels tend to increase the amount of water trapped in the soil, which in turn reduces the dry density of the soil. This reflects the physical phenomenon whereby the addition of calcium to the soil can affect the structure and density of the soil, especially at higher calcium levels.

b. Mechanical Properties (Unconfined)

Unconfined compressive strength of soil to determine strength values using cylindrical samples resulting from compaction. Unconfined uses a compression machine to compress cylindrical samples from one direction. This test uses a compression machine to compress artificial cylindrical samples from one direction (uniaxial).

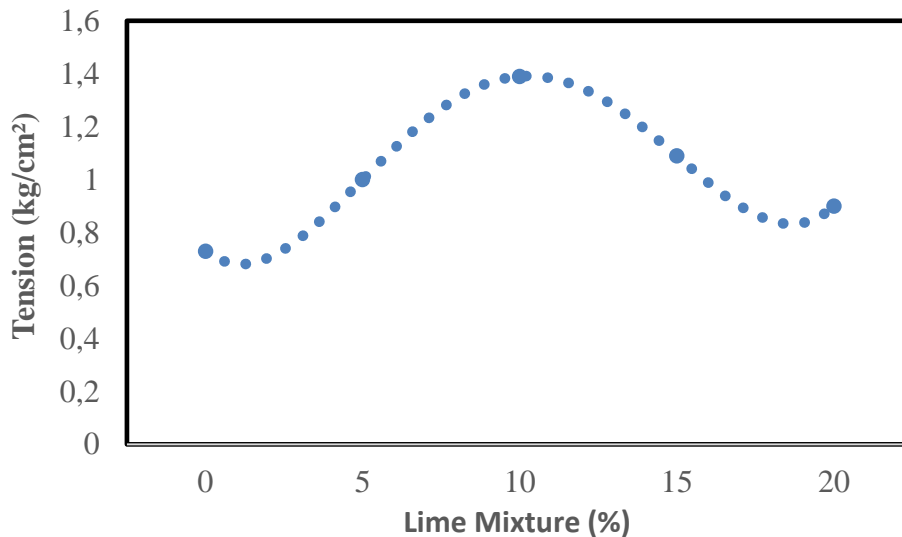


Figure 8 shows the relationship between lime mixture and unconfined soil stress.

Figure 8 shows that the unconfined stress of soft clay soil and the lime mixture above indicates that the clay soil stress fluctuates frequently with the addition of stabilizing materials. For 100% stabilized sand soil with 0% lime, the result is 0.73 kg/cm², followed by 95% stabilized soil with 5% lime, which increases to 1.00 kg/cm², then for a mixture of 90% soil with 10% lime (), the value is 1.39 kg/cm², for a mixture of 85% soil with 15% lime, the soil stress value decreases again to 1.09 kg/cm², and for the last mixture of 80% soil with 20% lime, the soil stress decreases to 0.90 kg/cm².

3. Determining the Optimum Level of Lime Mixing with Soft Baruk Surabaya Soil

The regression equation for analyzing the optimum lime content (Y) is $Y = -0.0047x^2 + 0.1018x + 0.7042$; $R^2 = 84.5\%$. Based on the quadratic equation, the maximum lime mixture occurs at a mixture of $(0.1018/(2*0.0047)) = 11\%$. Therefore, to achieve the highest granulometry, the best clay mixture is 10.83%.

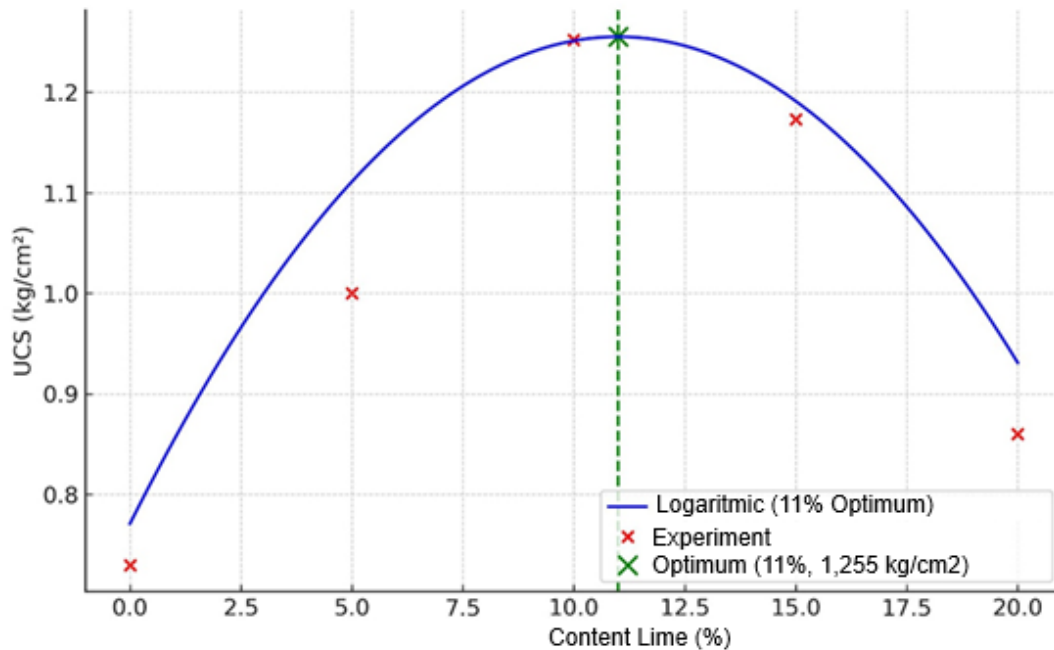


Figure 9 Regression analysis graph of the optimum lime content of soft clay soil.

Figure 9 shows that there is a significant difference between each lime content and the unconfined compressive strength value of the soil. The calculated F value, which is much greater than the F table at a significance level of 5%, confirms that lime content is a factor that influences the increase in soil strength.

Furthermore, to determine the optimum lime content, a quadratic regression analysis was performed on the UCS data. The results show that the optimum lime content is obtained at 11%, with a maximum strength of 1.26 kg/cm² and an R² value of 0.8481. This value indicates that the regression model is quite good at predicting the relationship between lime content and soil strength.

CONCLUSION

1. Mixing 5%, 10%, 15%, and 20% lime into soft soil at Gedung Baruk Surabaya improved its physical properties. The water content of the lime mixture caused a decrease in soil water content. The original soil had a moisture content (w) of 59.14%. When mixed with 5% lime, the moisture content decreased to 53.23%; when mixed with 10% lime, it decreased to 45.23%; when mixed with 15% lime, it decreased to 39.45%; and when mixed with 20% lime, it decreased to 30.35%. Meanwhile, the specific gravity of the lime mixture increases. For the original soil specific gravity of 2.17, mixing with 5% lime results in 2.76, mixing with 10% lime results in 2.80%, mixing with 15% lime results in 2.85, and mixing with 20% lime increases the specific gravity to 2.90. Meanwhile, the addition of lime causes the plasticity index to decrease. For the

original soil, the plasticity index value (5.82%) when mixed with 5% lime becomes (5.50%), when mixed with 10% lime the plasticity index becomes (3.37), when mixed with 15% lime it becomes (2.84%), and when mixed with 20% lime it becomes 1.55%.

2. Mixing 5%, 10%, 15%, and 20% lime into the soft soil of Gedung Baruk Surabaya resulted in improved soil mechanical properties. The dry weight of the lime mixture caused an increase in dry weight. The original soil had a dry weight of 2.80%. When mixed with 5% lime, the dry weight became 2.81%. When mixed with 10% lime, the dry weight increased to 2.85%. When mixed with 15% lime, the dry weight increased to 2.90%. and mixing with 20% lime resulted in a decrease in dry weight to 2.45%. The results of unconfined testing of the original soil and the lime mixtures above show that the soil stress fluctuates with the addition of stabilizing materials. For Surabaya's new soil, the value is 0.73 kg/cm², then the original soil is mixed with 5% lime and the soil stress value increases to 1.00 kg/cm². Then, for a composition of 10% native soil and mixture, the soil stress value increased again to 1.39 kg/cm². Then, in a mixture composition of 15%, the soil stress value decreased to 1.09 kg/cm². And in the final mixture composition of 20%, the soil stress decreased to 0.90 kg/cm².
3. The optimum percentage of lime for improving the physical and mechanical properties of Kedung Baruk soil is a mixture of 11% lime.

REFERENCES

- [1] A. L. Ramírez and L. Korkiala-Tanttu, "Stabilization of Malmi soft clay with traditional and low-CO₂ binders," *Transp. Geotech.*, vol. 38, no. December 2022, 2023, doi: 10.1016/j.trgeo.2022.100920.
- [2] K. Kunchariyakun *et al.*, "Mechanical and microstructural properties of cement-stabilized soft clay improved by sand replacement and biochar additive for subgrade applications," *Dev. Built Environ.*, vol. 20, no. July, p. 100552, 2024, doi: 10.1016/j.dibe.2024.100552.
- [3] M. H. Hatefi, M. Arabani, M. Payan, and P. Zanganeh Ranjbar, "The influence of volcanic ash (VA) on the mechanical properties and freeze-thaw durability of lime kiln dust (LKD)-stabilized kaolin clayey soil," *Results Eng.*, vol. 24, no. September, p. 103077, 2024, doi: 10.1016/j.rineng.2024.103077.
- [4] J. Konkol and W. Tisler, "Engineering properties of submerged organic silt stabilized with F-class fly ash," *J. Rock Mech. Geotech. Eng.*, no. xxxx, 2025, doi: 10.1016/j.jrmge.2025.03.058.
- [5] Y. dan Sun *et al.*, "Experimental study and machine learning prediction on compressive strength of industrial waste- solidified marine soft soil under dry-wet cycles," *Case Stud. Constr. Mater.*, vol. 23, no. April, p. e04943, 2025, doi: 10.1016/j.cscm.2025.e04943.
- [6] X. Wang, S. Kim, Y. Wu, Y. Liu, T. Liu, and Y. Wang, "Study on the optimization and performance of GFC soil stabilizer based on response surface methodology in soft soil stabilization," *Soils Found.*, vol. 63, no. 2, p. 101278, 2023, doi: 10.1016/j.sandf.2023.101278.
- [7] S. Bozkurt, J. Dijkstra, and M. Karstunen, "Transportation Geotechnics Influential factors on the performance of embankments stabilised on deep-

- mixed columns,” *Transp. Geotech.*, vol. 55, no. July, p. 101643, 2025, doi: 10.1016/j.trgeo.2025.101643.
- [8] W. Hou, J. Wang, D. Feng, S. Liang, F. Liu, and S. Wu, “Experimental Study on Mechanical Properties of Sodium Silicate-Activated Slag/Fly Ash Solidified South China Coastal Soft Soil: Areas of specialization: Geotechnical Engineering,” *KSCE J. Civ. Eng.*, vol. 29, no. 5, p. 100125, 2025, doi: 10.1016/j.kscej.2024.100125.
- [9] S. Fulambarkar, B. Manna, and J. T. Shahu, “Effect of deep mixed column pattern on the performance of basal reinforced embankment resting on soft soil,” *Soils Found.*, vol. 65, no. 2, p. 101578, 2025, doi: 10.1016/j.sandf.2025.101578.
- [10] M. H. Hatefi, M. Arabani, M. Payan, and P. Z. Ranjbar, “Impact of recycled macro-synthetic fibers on kaolin soil stabilized with lime kiln dust and volcanic ash,” *Case Studies in Construction Materials*, vol. 22, no. May, p. e04830, 2025, doi: 10.1016/j.cscm.2025.00000. *Constr. Mater.*, vol. 22, no. May, p. e04830, 2025, doi: 10.1016/j.cscm.2025.e04830.
- [11] Z. Sun, W. Chen, R. Zhao, N. Malik, J. Yin, and Y. Chen, “Investigation on solidified/stabilized behavior of marine soil slurry by lime-activated incinerated sewage sludge ash-ground granulated blast furnace slag under multifactor conditions,” *J. Rock Mech. Geotech. Eng.*, vol. 16, no. 12, pp. 5264–5277, 2024, doi: 10.1016/j.jrmge.2024.02.037.
- [12] P. Joyklad *et al.*, “Environmentally friendly binders from calcium carbide residue and silica fume and feasibility for soft clay stabilization,” *Case Stud. Constr. Mater.*, vol. 20, no. January, p. e03117, 2024, doi: 10.1016/j.cscm.2024.e03117.
- [13] K. Rangaswamy and R. P. Mohan, “Strengthening subgrade clay soil using nano-chemical stabilisation with *Soils and Foundations*, vol. 65, no. 4, p. 101638, 2025, doi: 10.1016/j.sandf.2025.101638.
- [14] A. T. Sudjianto, A. D. C. D. J. Vili, A. Suraji, R. Riman, and S. H. Susilo, “The effect of adding quicklime on stabilization of expansive soils,” *Technol. Audit Prod. Reserv.*, vol. 2, no. 3(82), pp. 12–17, 2025, doi: 10.15587/2706-5448.2025.326784.
- [15] A. N. Tavala and A. Tabaroei, “Sustainable clay soil stabilization using construction waste: Mechanical behavior, engineering parameters, and microstructural analysis,” *Results Eng.*, vol. 27, no. July, p. 106247, 2025, doi: 10.1016/j.rineng.2025.106247.
- [16] R. Hong Zhang, J. Jin Zhou, X. Nan Gong, W. Ming, and T. Wang, “Experimental and DEM simulation on engineering properties of soft soil stabilized by industrial solid waste – cement synergy,” *Case Studies in Construction Materials*, vol. 22, no. September 2024, p. e04852, 2025, doi: 10.1016/j.csc.2024.00000. *Constr. Mater.*, vol. 22, no. September 2024, p. e04852, 2025, doi: 10.1016/j.cscm.2025.e04852.
- [17] N. Li *et al.*, “Enhancement effect of calcium carbide residue and rice husk ash on soft soil: Small-strain property and micro mechanism,” *J. Mater. Res. Technol.*, vol. 32, no. June, pp. 774–791, 2024, doi: 10.1016/j.jmrt.2024.07.170.
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