Subgrade Stabilization with Ca $(OH)_2$ Lime to Improve the Physical and Mechanical Properties of Soil (Case Study: The National Road Trengguli – Bts. Kab. Demak/Kudus)

Rahmadsyah Rangkuti[1,a)], Ria Asih Aryani Soemitro[2,b)], Dwa Desa Warnana[3,c)] Trihanyndio Rendy Satrya[4,d)] & Yanuar Dwi Putra[5,e)]

[1)]Magister Student, Civil Engineering Department, Institut Teknologi Sepuluh Nopember, Surabaya,Indonesia
[2)]Civil Engineering Department, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
[3)]Geophysical Engineering Department, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
[4)]Geophysical Engineering Department, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
[5)] The National Road Construction Agency (BBPJN) for Central Java – Special Region of Yogyakarta, Directorate General of Highways, Ministry of Public Work and Housing (PUPR), Semarang, Indonesia

Correspondent: [a)]rahmadsyah.rangkuti@pu.go.id, [b)]soemitroraa@gmail.com, [c)]dwa_desa@yahoo.co.uk, [d)]trendysatrya@gmail.com & [e)]bbpjn_jatengdiy@pu.go.id

ABSTRACT

Road damage on The National Road Trengguli - Bts. Kab. Demak/Kudus in the form of cracks and collapses, the contributing factors are soft subgrade conditions and irrigations on both sides of the road. Chemical stabilization with $Ca(OH)_2$ lime can improve the soil's mechanical and physical characteristics. This research uses the addition of lime with variations of 2%, 4%, 6%, 7%, 8%, and and 10% of the soil's dry weight. Based on the standard proctor test results, the optimum mixture of 6% lime was obtained with a value of γ_{dmax} = 1.459 gr/cm^3 and W_{opt} = 28.052%. Furthermore, the original soil and 6% lime mixture were tested: sieve and hydrometer analysis, Atterberg limits, standard proctor compaction, unconfined compressive strength (UCS), laboratory CBR (soaked) and 1 cycle drying - wetting testing. At 6% lime for UCS and CBR testing, 0, 7 and 14 days of curing were conducted. The results of research on the initial soil and after 6% lime stabilization, namely the soil classification based on USCS originally included in CH, namely non-organic loamy soil with high plasticity or fat clays to SM, namely silty sand and based on AASHTO originally included in A-7-6 clay soil to A-7-5 clay soil, from PI = 43.232% to PI = 16.213%, from CBR = 0.917% to CBR with 0, 7, and 14 days of curing are 11.463%, 14.266%, and 19.408%, from qu = 0.967 kg/cm^2 to qu with 0, 7, and 14 days of curing are 2.973 kg/cm^2, 9.546 kg/cm^2 and 12.206 kg/cm^2. After 1 cycle drying - wetting test, there is a decrease in qu value, namely in the initial soil of 93.004% and 6% lime stabilized soil of 73.040%.

Keyword : soft soil, subgrade, lime stabilization, drying – wetting.

INTRODUCTION

Infrastructure is any kind of structure made by people to fulfill the requirements of public life, and private life such as: dams, roads, bridges, drainage, irrigation, wastewater treatment plants, railroads, ports, airports, etc. (Suprayitno & Soemitro, 2018). There are four sectors within Public Works and Housing Infrastructure, and they are as follows: Infrastructure related to public housing, road and bridge construction, sanitation, and water resources (Suprayitno & Soemitro 2016). According to Suprayitno and Sumitro (2020), infrastructure needs to be maintained in order for it to remain in excellent condition and perform as intended. Infrastructure Asset Management is the notion that it must adhere to in order to produce this. The science, program, and expertise for managing facilities and infrastructure across the course of their lives is known as infrastructure and facility asset management, or IFAM. IFAM's primary goal is to guarantee that facilities and infrastructure may operate in an economically, efficiently, and effectively sustainable manner while adhering to ecologically friendly principles (Maulidha, Satrya & Lastiasih, 2022).

Roads are the locomotive to drive economic development not only in urban areas but also in rural areas. Roads are very important in maintaining the pulse of the economy. This cannot be separated from its role in supporting human movement and affecting distribution and logistics activities. The National Road Trengguli - Bts. Kab. Demak/Kudus is a national road in Central Java Province that plays a significant part in the economic development of the country and the region. **Figure 1** shows the location of The National Road Trengguli - Bts. Kab. Demak/Kudus which is under the authority of the Commitment Making Officer 3.1 of the Central Java Province National Road Implementation Center's Special Region of Yogyakarta, through the Central Java Province National Road Implementation Work Unit.

The length of The National Road Trengguli - Bts. Kab. Demak/Kudus is 13.36 km. This section is included in the Pantura Line with heavy traffic load volume, consisting of 4 lanes 2 directions with median (4/2D). The position of the road is flanked by waterways on both sides and sometimes floods, so the road becomes submerged. On the left side of the road (normal direction) in addition to the edge channel, there is also an irrigation channel, where the water level is almost parallel to the road surface. There are irrigation channels on the right and left sides of the road as shown in **Figure 2**. Damage to rigid pavement generally occurs in the slow lane even though there is also damage to the fast lane, but with a lower intensity. According to information from PPK, road construction was carried out in the period 2013-2015 where there was widening on both sides, so that the road width became 8.5 m for each lane. The fast lane is at the location of the old existing road and the slow lane is the widening lane.

Figure 1. Location of The National Road Trengguli - Bts. Kab. Demak/Kudus
Source : PPK 3.1 Central Java Province, 2023

Figure 2. Irrigation on both sides
Source : Google Map, 2023

Based on the results of the field review, it can be seen that The National Road Trengguli - Bts. Kab. Demak/Kudus, there is damage in the form of cracks and collapses, especially in the slow lane and on the pavement on the shoulder of the road, besides that there is also a shift in the shoulder and road border as shown in **Figures 3**.

The cracking on the main lanes of this section is quite severe, especially on the slow lanes. The types of cracks vary from longitudinal cracks, transverse cracks, corner cracks and block cracks. The dominant damage on the slow lane is likely due to the less stable bottom condition compared to the fast lane, because the slow lane is a widened lane while the fast lane is an existing lane of the old road, so the carrying capacity conditions are more stable, this condition is exacerbated by the presence of irrigation channels on both the left and right sides of the road. Damage to the shoulder is generally in the form of longitudinal cracks and a decrease of 5 - 7 cm in depth, possibly caused by movement in the soft subgrade.

Figures 3. Road damage that occurs
Source : BPLJ, 2021

From the results of Boring Testing at 2 points with a depth of 20 meters, the NSPT value is obtained in the range of 0 - 6. According to Bowles (1986), the soil is included in the consistency of very soft - soft soil as shown in **Table 1** and this is in line with the soft soil distribution map of Central Java Province (2019), where the area of Jalan Rengguli - Bts. Demak/Kudus is colored green which is soft soil as shown in **Figure 4**.

Table 1. Correlation between N-SPT and consistency of sand and clay

Noncohession soil				
N-SPT	0 - 10	11 - 30	31 - 50	>50
Density, γ (kN/m^3)	12 - 16	14 - 18	16 - 20	18 - 23
Internal Angle Friction, Ø	25 - 32	28 - 36	30 - 40	>35
Condition	Loose	Medium	Stiff	Very Stiff
Cohession soil				
N-SPT	<4	4 - 6	6 -15	16 - 25
Density, γ (kN/m^3)	14 - 18	16 -18	16 -18	16 -18
q_u (kPa)	<25	20 - 50	30 - 60	40 - 200
consistency	Very Soft	Soft	Medium	Stiff

Source : Bowles, 1986

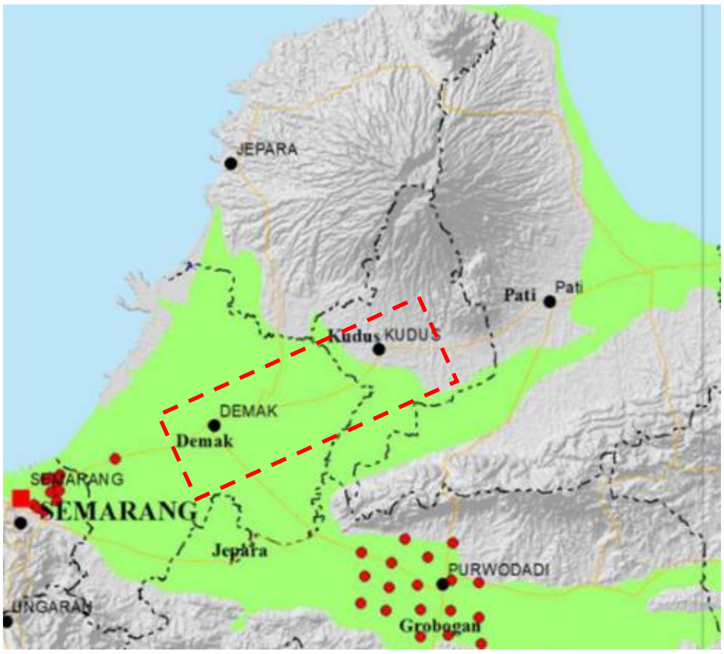


Figure 4. Map of soft soil distribution in Central Java Province
Source : Geological Agency, 2019

Subgrade is the most important part of a structure rigid pavement or flexible pavement, because the subgrade is the part that forms the foundation of a pavement. The durability and strength of the road also depends on the properties of the subgrade used for the pavement, including the thickness of the pavement is determined by the type of subgrade on which the pavement is based. The subgrade function will withstand the construction load above it, the subgrade must have a good soil bearing capacity, so that it can withstand the load that has been calculated before the pavement is built on it (Sukirman, 1999).

Chemical stabilization using lime is one technique for enhancing the mechanical and physical characteristics of soil. Soil stabilization with lime is basically the same as soil stabilization with cement, such as testing techniques and implementation. The difference is that lime is more suitable for soil stabilization for clay soils, and less suitable for granular soils. Quicklime or lime solution can be used for the treatment of excessively wet or dry soils. For highway applications, soil-lime stabilization is widely used for building subbase or subgrade improvements. Soil-lime stabilization has been widely used in highway, airport, railroad and road works projects in the project area (Hardiyatmo, 2022).

Based on previous research on soil stabilization with lime, natural soil mixture with 7% lime can increase the maximum dry density (γ_{dmax}) value by 7.289% (Limbong, 2023).

Changes in the rainy and dry seasons and the condition of The National Road Trengguli - Bts. Kab. Demak/Kudus have irrigation on both the left and right sides of the road, it has an impact on changes in soil water content, which affects the physical and mechanical characteristics of the soil.

According to the results of drying-wetting tests conducted in the laboratory to identify how water changes affect soil characteristics. It was discovered that the drying-wetting cycle had a significant impact on the mechanical and physical characteristics of the soil. The significant variation in the value of undrained shear strength, Cu (125 kPa) values during the drying-wetting cycle show that the cycle also influences these characteristics. According to Satrya et al. (2019), it may be inferred that the undrained shear strength value decreases with increasing cycle frequency.

LITERATURE REVIEW

Additive Selection Method

Hicks (2002) in Alaska Department of Transportation ang Public Facilities Research & Technology Transfer proposed a guideline for selecting stabilization materials, as shown in **Table 2**. In this method, the grain size distribution and Atterberg limits are used as the basis for assessing the type of stabilization to be used. The guidelines in **Table 2** are for preliminary consideration only, and can be used for soil modification purposes, such as: stabilization with lime to make the material drier and reduce its plasticity.

Table 2. Initial guidance for the selection of stabilization methods

Percentage Passing Sieve No. 200	**>25% Percentage Passing Sieve No. 200 (0.0075 mm)**			**< 25% Percentage Passing Sieve No. 200 (0.0075 mm)**		
Plasticity Index, PI (%)	≤ 10	10 - 20	≥ 20	≤ 6 PI x p ≤	≤ 10	≥ 10
Stabilization materials :						
Cement and binder mix	Match	Doubt	Not Match	Match	Match	Match
Lime	Doubt	Match	Match	Not Match	Doubt	Match
Asphalt (bitumen)	Doubt	Doubt	Not Match	Match	Match	Doubt
Asphalt/cement mix	Match	Doubt	Match	Match	Match	Doubt
Granular	Match	Not Match	Not Match	Match	Match	Doubt
Other mixtures	Not Match	Match	Match	Not Match	Doubt	Match

Source : Hicks, 2002

Soil Reaction with Lime

Calcium ions (Ca^{2+} and Mg^{2+} ions) become abundant when lime is added to the soil. These Ca ions tend to displace common cations, such as sodium (Na^{+}) or potassium (K^{+}) on clay particles. This process is called cation exchange. When calcium is substituted by sodium or potassium, the clay particle's plasticity index will be significantly lower. The addition of lime raises the soil's pH and cation exchange capacity at the same time.

Consequently, despite the soil's high calcium content, After stabilizing the soil with lime, the soil's plasticity will decrease. The decrease in plasticity is generally followed by a decrease in the shrinkage-deflection potential of the soil, a decrease in the ease of loss of strength by changes in water content, and a decrease in stickiness (Rollings and Rollings, 1996).

Soil Water Characteristic Curve (SWCC)

Soil water characteristic curve (SWCC) has been widely used in the calculation of unsaturated soil characteristics (Fredlund 1995, 2000). The SWCC is now an important factor in the mechanics of unsaturated soils, particularly in geotechnical engineering research. The procedure of calculating unsaturated soil characteristics has been proposed for almost every physical process when soil becomes unsaturated (Fredlund 1995; 2000). The corresponding data on SWCC is plotted on a graph of the interaction between water content and suction. The general form of the SWCC graph can be seen in **Figure 5**. There are two very important points of difference on the graph (Fredlund 1995, 2000). The first point is the "air entry value" of the soil, where the presence of very large pores starts to make the soil unsaturated. The second point is the "residual condition", at which point water loss in the soil becomes more difficult. Changes in the slope of the curve on the graph are divided into three parts; the first is the "boundary effect zone" which has a low suction value, the second is the "transition zone" which has an area between the air entry value and residual value, and the last is the "residual zone" which is at a high suction value of up to 1,000,000 kPa. All SWCC graphs will give the same characteristics as mentioned above.

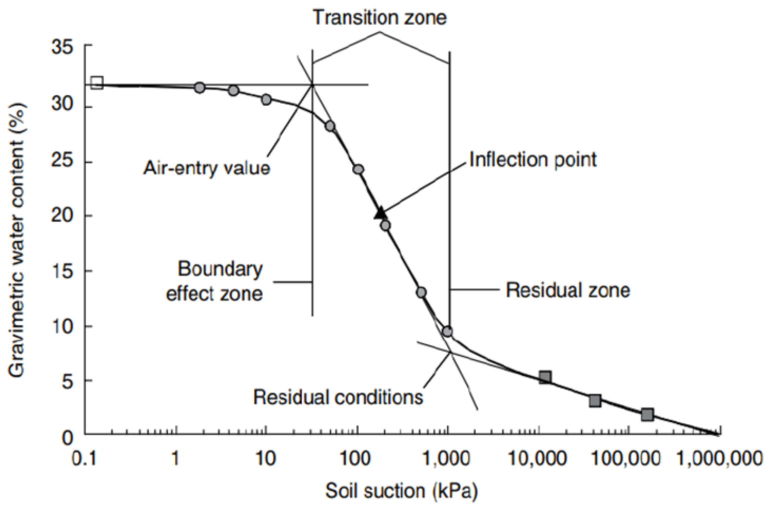


Figure 5. General shape of Soil-Water Characteristic Curve (SWCC)
Fredlund and Rahardjo, 1993

RESEARCH METHOD

In this research, the original soil was tested: sieve and hydrometer analysis, limits of atterberg, unconfined compressive strength, proctor compaction standard, laboratory CBR (soaked) and 1 cycle drying - wetting testing. Furthermore, the addition of lime using variations of 2%, 4%, 6%, 7%, 8%, and 10% of the dry weight of the soil. To find out the most optimum lime mixture of soil + lime samples, compaction testing was carried out with a standard proctor that refers to SNI 1742: 2008. Compaction testing with standard proctor to obtain a compaction curve, which is the correlation between water content (W_c) and soil dry density (γ_d). Based on the curve of compaction, the price of maximum dry density (γ_{dmax}) and optimum moisture content (W_{opt}) can be determined. Furthermore, the optimum lime mixture soil was tested: sieve and hydrometer analysis, limits of atterberg, proctor compaction standard, unconfined compressive strength, laboratory CBR (soaked) and 1 cycle drying - wetting testing. At 6% lime, the UCS and CBR tests were conducted for 0, 7 and 14 days.

The specimens used in testing the drying-wetting process for the initial soil and initial soil with optimum lime addition used disturbed soil samples. For the purpose of evaluating unconfined compressive strength, the test specimens were molded using PVC pipes. The diameter of the samples was 3.85 cm, and their height was 8.00 cm. For the purpose of testing volumetric-gravimetric and suction, the test specimens were 3.85 cm in diameter and 2.00 cm in height. This test is perfomed in stages based on the percentage of reduction and addition with a range per 25% moisture content. Conditioning the reduction and addition of water (difference of water content) can be written with the following formula:

Difference of water content (%) = (W_{sat} - W_{airdry})/4 …(1)

Where :
W_{sat} = W_{+100} = water content at saturated condition (%)
W_{airdry} = W_{-100} = water content at air dry condition (%)

To determine the value of water content in W_{airdry}conditions, namely by drying the test specimens in air-dry conditions by drying the test specimens in the sun, then weighing the test specimens to check the water content. W_{airdry} conditions are achieved if the water content in the test specimen does not decrease again (constant water content). Meanwhile, to get the value of water content at saturated conditions (W_{sat}) with the formula:

$$W_{sat} = \frac{e}{Gs}\ x\ 100\% \quad \text{…(2)}$$

Where :
W_{sat} = water content at saturated condition (%)
e = void ratio (%)
Gs = specific gravity

In the drying - wetting test, for each water content range, volumetric-gravimetric, unconfined compressive strength and suction were conducted. Each test specimen to be sought for suction was given a circular Whatman No. 42 filter paper with a diameter of 2.7 cm. To avoid damage or dirty, the installation of whatman filter paper No. 42 is coated with ordinary filter paper with a diameter of 3.85 cm at the bottom and top of whatman filter paper No. 42.

DATA COLLECTION

Based on the data obtained from boring test results by the Satker P2JN central java province on The National Road Trengguli - Bts. Kab. Demak/Kudus, the SPT value of 0-6 is obtained at a depth of 0-20 meters, so the soil is included in the characteristics of very soft - soft soil (Bowles, 1986).

In this study, soil sampling was carried out on the The National Road Trengguli - Bts. Kab. Demak/Kudus KM. 41+700 (6.86115467S 110.77905406E), Demak Regency, Central Java Province. The soil samples taken consisted of disturbed and undisturbed soil samples. Soil sampling was carried out during the process of excavating the foundation of the retaining wall work at that location. Disturbed soil samples were taken at a depth of 2.60 m and undisturbed soil samples at a depth of 3.00 m from the road shoulder. The number of samples taken include the following:

1. Disturbed soil samples as much as ± 450 kg.
2. Undisturbed soil samples as many as 3 shelby tubes.

Testing of characteristics of soil, both mechanical and physical carried out at the Laboratory of Soil and Rock Mechanics FTSPK ITS Surabaya. Tests of physical properties carried out include: sieve and hydrometer analysis tests, volumetric-gravimetric tests and consistency tests, while for mechanical tests carried out include: proctor standard compaction test, unconfined compressive strength test and laboratory CBR test.

RESEARCH ANALYSIS

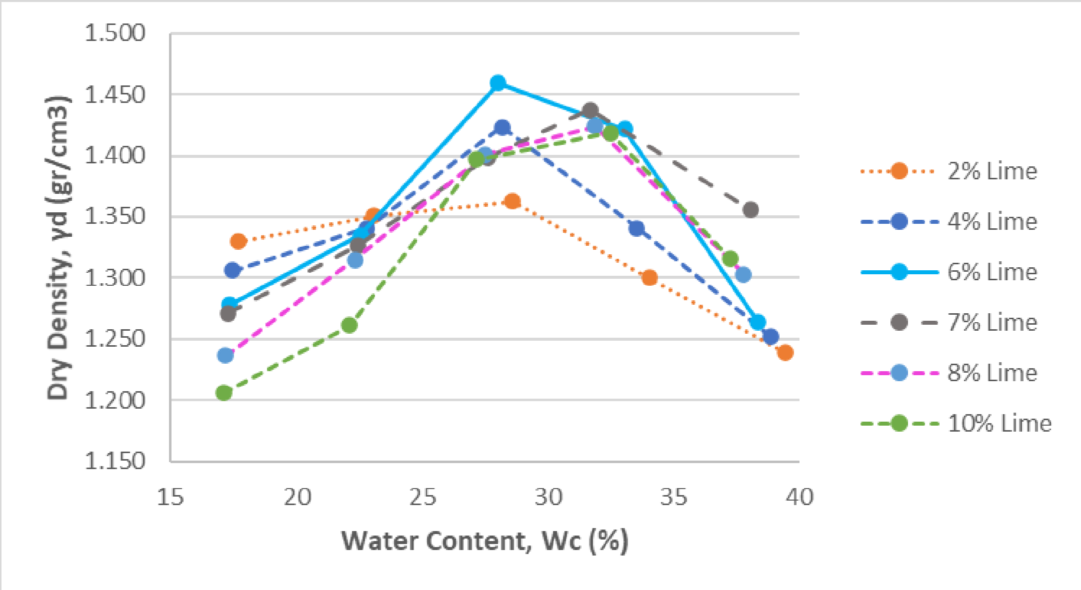
From the results of standard proctor compaction testing of the initial soil + lime mixture with 2%, 4%, 6%, 7%, 8% and 10% lime variations, the optimum lime content was obtained in the 6% soil + lime mixture which produced the highest maximum dry density (γ_{dmax}) is 1.459 gr/cm^3 with an optimum moisture content (W_{opt}) at 28.052% shown in **Table 4** and **Figure 6**. Then for soil mixtures with 6% lime (optimum lime mixture), physical properties were tested including: sieve and hydrometer analysis tests, volumetric-gravimetric tests and consistency tests, while for mechanical testing, variations in curing for 0, 7 and 14 days were carried out on: unconfined compressive strength and soaked laboratory CBR test. The physical and mechanical characteristics test results of the initial soil and the initial soil with the addition of 6% lime can be seen in **Table 3**. The unconfined compressive strength and Laboratory CBR test results for 0, 7 and 14 days of curing can be seen in **Figure 7** and **Figure 8**.

Table 3. The results of comparing the initial soil's mechanical and physical characteristics with the addition of 6%

No.	Description	Inisial Soil	Inisial Soil with 6% lime addition
1	**Physical Properties Test**		
a	Sieve and Hydrometer Analysis Test		
	- *Gravel*	1.251 %	20.645 %
	- *Sand*	12.118 %	29.940 %
	- *Silt*	24.631 %	25.915 %
	- *Clay*	62.000 %	23.500 %
b	Volumetric - Gravimetric Test		
	- Water Content (*Wc*)	37.461 %	28.051 %
	- Specific Gravity (Gs)	2.636	2.779
	- Density (ϒt)	1.677 gr/cm^3	1.868 gr/cm^3
	- Dry Density (ϒd)	1.220 gr/cm^3	1.459 gr/cm^3
	- Void Ratio (e)	1.161 %	0.905 %
	- Porosity (n)	53.724 %	47.501 %
	- Degree of Saturation (Sr)	85.029 %	86.157 %
c	Atterberg Limits Test		
	- Liquid Limit (LL)	71.733 %	62.029 %
	- Plastic Limit (PL)	28.501 %	45.816 %
	- Shrinkage Limit (SL)	17.328 %	44.592 %
	- Plasticity Index (PI)	43.232 %	16.213 %
2	**Mechanical Properties Test**		
a	Standard Proctor Compaction Test		
	- Optimum Moisture Content (OMC)	26.051 %	28.053 %
	- Maximum Dry Density (MDD)	1.326 gr/cm^3	1.459 gr/cm^3
b	Unconfined Compressive Strength (qu)		
	- 0 day curing period	0.967 kg/cm^2	2.973 kg/cm^2
	- 7 days curing period		9.546 kg/cm^2
	- 14 days curing period		12.206 kg/cm^2
c	CBR Laboratory (soaked)		
	- 0 day curing period	0.917 %	11.463 %
	- 7 days curing period		14.266 %
	- 14 days curing period		19.408 %
3	**Soil Classification**		
	- USCS	CH	SM
	- AASTHO	A-7-6	A-7-5

Source : Author, 2024

Based on based on table 2 indicates that the addition of 6% lime causes an increase in the values of: soil grain size, plastic limit (PL), shrinkage limit (SL), specific gravity (Gs), density (γt), dry density (γd), degree of saturation (Sr), maximum dry density (γ_{dmax}), unconfined compressive strength (qu), and Laboratory CBR (soaked), while the values: liquid limit (LL), plasticity index (PI), water content (Wc) and void ratio (e) decrease. The increase and decrease in the value of physical and mechanical properties is caused by the soil - lime reaction which includes contact between clay minerals and pozzolanic components with lime materials, ion exchange occurs and then a calcium silica gel is formed which will not be broken down with water so that the flocculation process occurs. The next stage of silica gel will envelop and bind the clay soil and cover the soil pores. Then the gel will crystallize to form hydrated calcium silica ($CaSiO_3$) and these small crystals can bind to each other, this process can also be called cementation, this cementation process reduces the water in the soil, thereby reducing the properties of plasticity in the soil, reducing soil pores, increasing soil grain size and increasing soil strength. The value of soil parameters stabilized with 6% lime is better than the initial soil.



Source : Author, 2024

Figure 6. Standard proctor compaction test results of initial soil with 2%, 4%, 6%, 7%, 8% and 10% lime addition variations

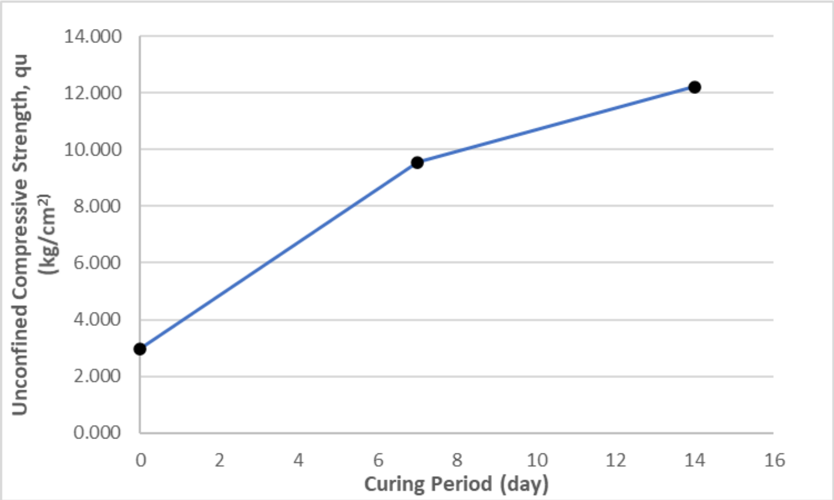
Based on based on **Figure 6** demonstrates that the addition of a percentage of lime exceeding 6% shows a decrease in the maximum dry density (γ_{dmax})value, because the greater the amount of lime added, the cementation process will be reduced due to the lime not being fully hydrated, decreasing the strength of the soil mixture with lime as a result of a decrease in the binding between the soil and the lime.

Table 4. Maximum dry density value of initial soil with 2%, 4%, 6%, 7%, 8% and 10% lime addition variations

No.	Lime Content (%)	*Maximum Dry Density* (gr/cm^3)	*Optimum Moisture Content* (%)
1	2	1.362	28.602
2	4	1.423	28.186
3	6	1.459	28.052
4	7	1.437	31.680
5	8	1.424	31.890
6	10	1.418	32.476

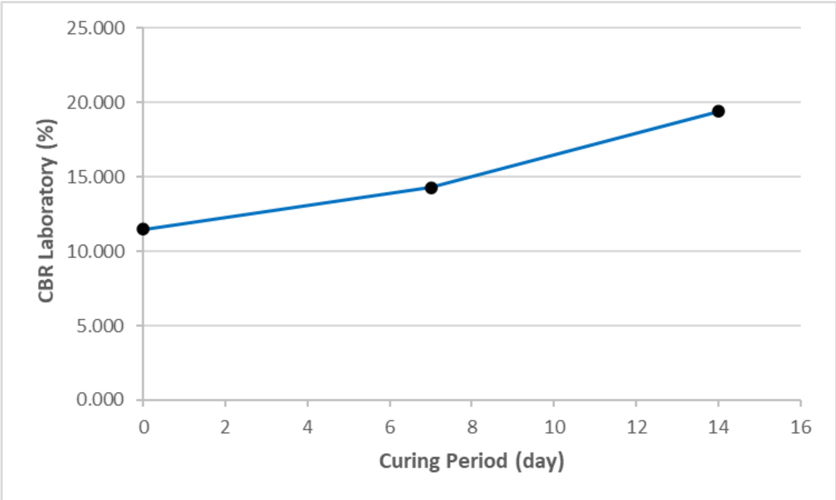
Source : Author, 2024

Based on based on **Table 4** indicates that the greater the addition of lime, the greater the optimum moisture content value, this is because the greater the amount of lime added, the more water is absorbed in the mixture.



Source : Author, 2024

Figure 7. The unconfined compressive strength test results for 0, 7 and 14 days of curing initial soil with 6% lime addition

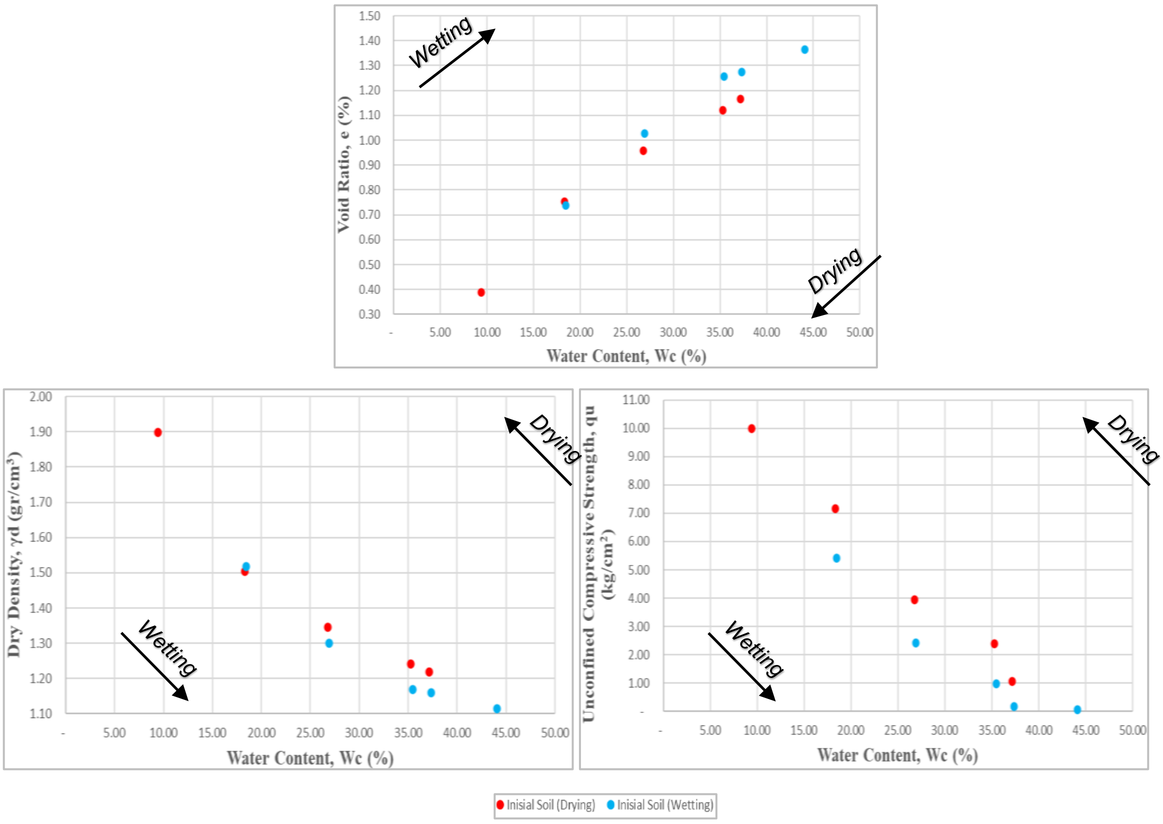


Source : Author, 2024

Figure 8. The CBR Laboratory (soaked) test results for 0, 7 and 14 days of curing initial soil with 6% lime addition

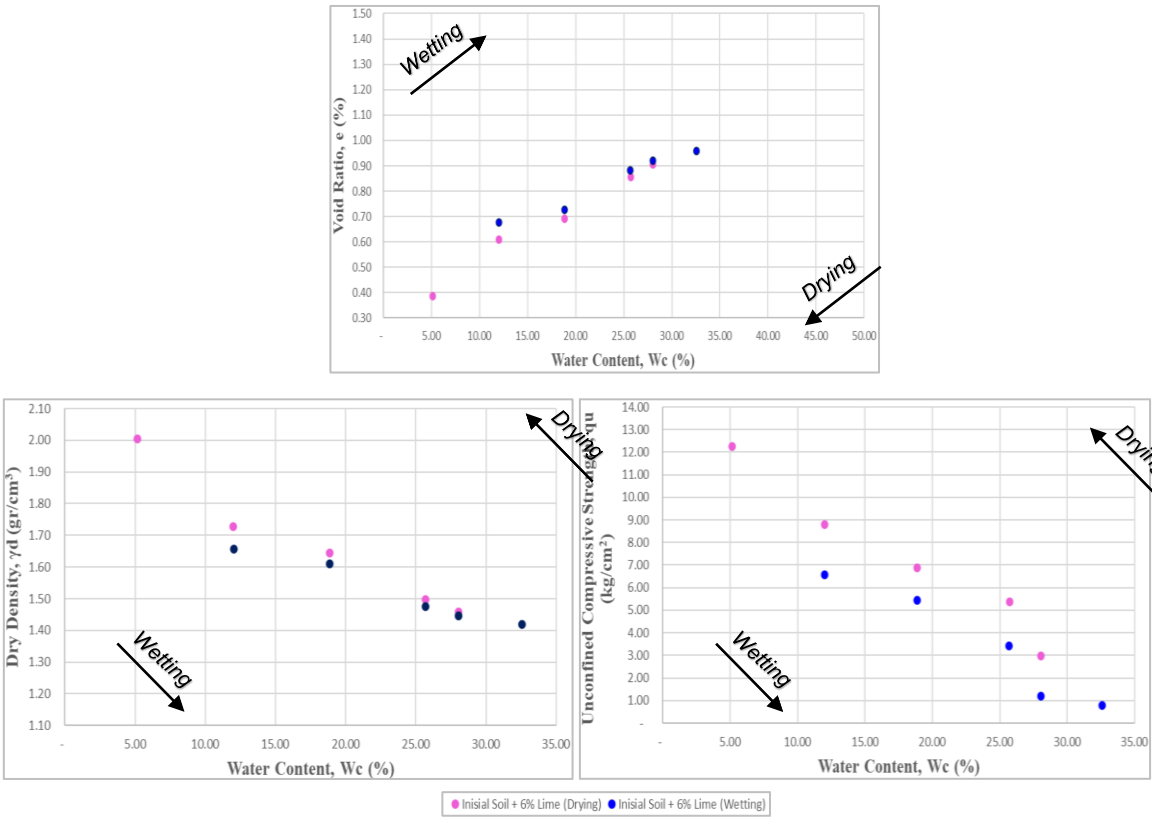
Based on based on **Figure 7** and **Figure 8** shows that the longer the curing period, the higher the unconfined compressive strength and CBR values, this is because the cementation reaction that occurs between the soil and lime is more perfect, thus increasing the compressive strength and bearing capacity of the soil.

Test Results Drying - Wetting Initial soil and initial soil with the addition of 6% lime shown in **Figure 9** and **Figure 10**.



Source : Author, 2024

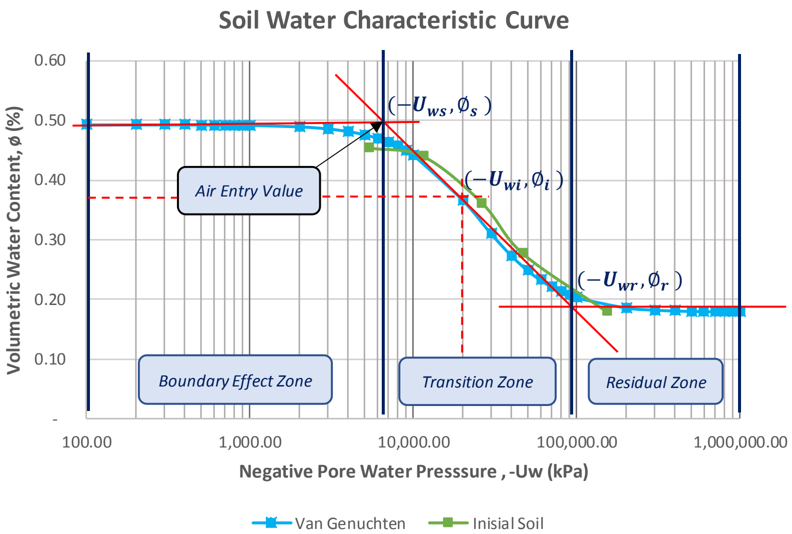
Figure 9. Effect of drying – wetting of inisial soil on void ratio, dry density and unconfined compressive strength values



Source : Author, 2024

Figure 10. Effect of drying – wetting of inisial soil with 6% lime addition on void ratio, dry density and unconfined compressive strength values

Based on **Figure 9** and **Figure 10**, it can be concluded that after 1 cycle of drying - wetting tests on the initial soil and initial soil with 6% lime addition, the dry density of soil (γ_d) and unconfined compressive strength (qu) values decrease, while the void ratio (e) value increases. The decrease in soil dry density (γ_d) value of the initial soil was 8.420% and the initial soil with 6% lime addition was 2.804%. The reduction in the unconfined compressive strength (qu) value of the initial soil was 93.004% (medium to very soft consistency) and the initial soil with 6% lime addition was 73.040% (very stiff to medium consistency). The increase in the void ratio (e) value of the initial soil by 17.082% and the initial soil with 6% lime addition by 5.500%. The increasing value of water content (Wc), the decreasing value of soil dry density (γ_d), because the cavity in the soil is filled with water, so that the void ratio (e) becomes larger, the increase in void ratio (e) illustrates the increase in voids (voids) in the soil so that the soil capillary pipe increases which weakens the bond between particles, causing less contact between soil grains, thus causing a decrease in density, dry density (γ_d) and unconfined compressive strength (qu). The decrease in dry density (γ_d) and unconfined compressive strength (qu) values and the increase in void ratio (e) in the 6% lime stabilized soil are smaller than the initial soil, because the cementation reaction of the soil with the addition of 6% lime causes the soil parameters to be more stable against changes in water content that occur.

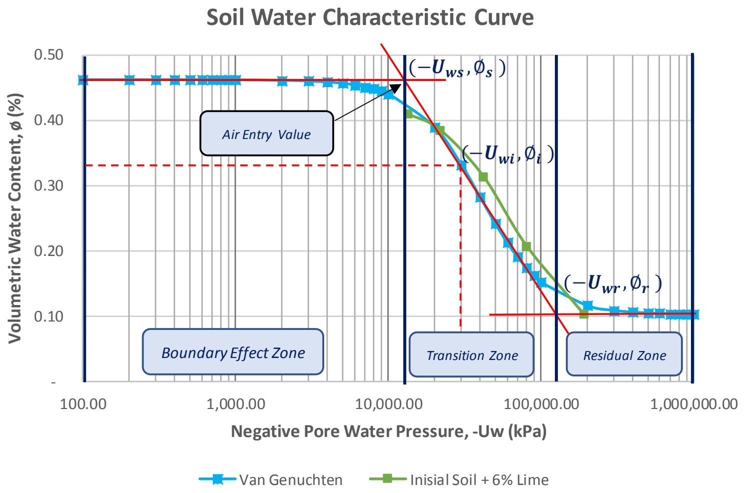


Source : Author, 2024

Figure 11. Fitting soil water characteristic curve (SWCC) of the initial soil using Van Genuchten function

According to the initial soil water characteristic curve (SWCC) fitting using the Van Genuchten function in **Figure 11** above, the values of the unsaturated soil parameters are obtained as follows:

- $\emptyset_s$ = 0.492
- AEV = 6,500 kPa
- $\emptyset_i$ = 0.370
- $\emptyset_r$ = 0.178
- m = 0.643
- n = 2.800



Source : Author, 2024

Figure 12. Fitting soil water characteristic curve (SWCC) of the initial soil with 6% lime addition using Van Genuchten function

According to the initial soil with 6% lime addition soil water characteristic curve (SWCC) fitting using the Van Genuchten function in **Figure 12** above, the values of the unsaturated soil parameters are obtained as follows:

- $\emptyset_s$ = 0.462
- AEV = 14,000 kPa
- $\emptyset_i$ = 0.330
- $\emptyset_r$ = 0.103
- m = 0.667
- n = 3.000

Table 5. Comparison of qu and CBR values of soil stabilization with 6% lime addition with previous studies

Parameters	Basriansyah (2007)		Author (2024)	
	Initial soil	Initial soil + 6% lime	Initial soil	Initial soil + 6% lime
$q_u\ (kg/cm^2)$	2.281	7.534	0.967	2.973
CBR (%)	1.570	2.525	0.917	11.463

Source : Basriansyah, 2007 & Author, 2024

According to table 5, after mixing the initial soil with 6% lime, the results of previous research by Basriansyah (2007) show that there is an increase in qu value by 230.29% and Laboratory CBR (Soaked) value by 60.83%, similar soil behavior is shown in the results of this study, namely an increase in qu value by 207.45% and Laboratory CBR (Soaked) value by 1150.05%.

Table 6. Comparison of γ_d and Cu values after 1 cycle drying - wetting test of initial soil and initial soil with 6% lime addition.

Parameters	Satrya (2018)		Author (2024)			
	Initial soil	After 1 cycle	Initial soil	After 1 cycle	Initial soil + 6% lime	After 1 cycle
$\gamma_d\ (gr/cm^3)$	1.292	1.206	1.218	1.115	1.459	1.418
$C_u\ (kg/cm^2)$	1.036	0.074	0.536	0.038	1.487	0.401

Source : Satrya, 2018 & Author, 2024

According to table 5, after drying - wetting 1 cycle testing on the initial soil, the results of previous research by satrya (2018) showed that there was a decrease in the yd value was 6.66% and the Cu value was 92.86%, similar soil behavior was shown in the results of this study, namely in the initial soil obtained a decrease in yd value was 8.46% and Cu was 92.91% and in the initial soil with the addition of 6% lime obtained a decrease in the yd value was 2.81% and the Cu was 73.03%.

CONCLUSION

According to the results of the analysis and discussion on the results of soil testing on the Trengguli Road section - Bts. Demak/Kudus Km. 41+700 consisting of initial soil samples and $Ca(OH)_2$ lime stabilization of physical and mechanical properties testing, 1 cycle drying - wetting testing, it can be concluded from this research as follows:

1. The results of testing the mechanical and physical characteristics of the initial soil obtained the following results: plasticity index (PI) = 43.232%. The soil classification according to USCS includes the CH category, namely non-organic clays with high plasticity or fat clays and based on AASHTO, it is categorized as A-7-6 clay soil type. Optimum moisture content (W_{opt}) = 26.051%, maximum dry density (γ_{dmax}) = 1.326 kg/cm2. The Unconfined compressive strength (qu) = 0.967 kg/cm2 (medium consistency). The laboratory CBR value (soaked) = 0.917%.
2. The optimum lime content was in the soil mixture with 6% lime which produced the highest maximum dry density (γ_{dmax}). The results of testing he mechanical and physical characteristics of the initial soil with 6% lime addition obtained the following results: plasticity index (PI) = 16.213%. The soil classification according to USCS includes the SM category, namely silty sand (sand-silt mixture) and based on AASHTO, it is categorized as A-7-5 clay soil type. Optimum moisture content (W*opt*) = 28.052%, unconfined compressive strength (qu) value of 0-day curing period = 2.973 kg/cm^2 is included in the very stiff consistency, 7-day curing period = 9.549 kg/cm^2 and 14-day curing period = 12.206 kg/cm^2 is included in the hard consistency. The laboratory CBR value (soaked) for the 0-day curing period = 11.463%, 7-day curing period = 14.266% and 14-day curing period = 19.408%.
3. After 1 cycle of drying - wetting tests on the initial soil and initial soil with 6% lime addition, the dry density of soil (γ_d) and unconfined compressive strength (qu) values decrease, while the void ratio (e) value increases. The decrease in soil dry density (γd) value of the initial soil was 8.420% and the initial soil with 6% lime addition was 2.804%. The decrease in the unconfined compressive strength (qu) value of the initial soil was 93.004% (medium to very soft consistency) and the initial soil with 6% lime addition was 73.040% (very stiff to medium consistency). An increase in the void ratio (e) value of the initial soil by 17.082% and the initial soil with 6% lime addition by 5.500%.

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