

Assessment Study of Drying Process Effect on Soil Cracks of Un-Treated and Lime Treated Bobonaro Clay

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ABSTRACT

Soil cracks and landslides are indeed major geotechnical challenges in the eastern sector of the Republic of Indonesia–Democratic Republic of Timor-Leste border section. When there is a change in weather from the rainy season to summer, cracks will appear on the Bobonaro clay, besides that there will be changes in the values of the physical and mechanical parameters of Bobonaro clay when exposed to weather. This research focused on crack behavior and analysis of changes in physical and mechanical properties due to the drying process. Laboratory tests will be carried out on 3 samples, namely initial soil conditions, compacted conditions, and soils treated using Ca(OH)_2 lime conditions. analysis of crack calculations or Crack Intensity Factor (CIF) values is carried out using matlab 2019a software. The value of the crack intensity factor (CIF) for the initial soil conditions at the end of the drying process was 2.5755% where there were cracks since the beginning of the drying process with crack patterns occurring in almost the entire sample from the edges to the middle of the sample. the value of crack intensity factor (CIF) on compacted soil conditions at the end of the drying process is 1.8787% which is smaller than the initial soil conditions, but the crack pattern is still large and has occurred since the beginning of the drying process. Soil treated with 7% lime had the smallest crack intensity factor (CIF) value at the end of the drying process of 0.5090% and had no crack pattern until the end of the drying process. This indicates that Ca(OH)_2 Lime is proven to be effective in reducing cracks for Bobonaro clay.

Keyword : Bobonaro Clay, Crack intensity factor (CIF), Crack analysis, Drying process, lime.

INTRODUCTION

The location of this research is on the island of Timor, there is the Motoain-Motomasin National Road Section, also known as the Eastern Sector Border Road, which is on the Republic Indonesia-Democratic Republic of Timor-Leste border. Figure 1 shows that this National Road also connects the Motoain State Border Crossing Post (PLBN) and the Motomasin State Border Post (PLBN) which are the outermost gates of the Republic of Indonesia.



Figure 1. Research Study Location (source: BPJN NTT, 2021)

Bobonaro clay on the Motoain-Henes-Motomasin National Road Section has special characteristics, Changes in physical parameters and mechanical parameters of Bobonaro clay only occur when exposed to weather and cause many cracks as shown in Figure 2. This is also supported by test data that has been carried out by the planning and supervision unit of East Nusa Tenggara province, BPJN East Nusa Tenggara.



Figure 2. Sta 149+140 Motoain-Henes-Motomasin National Road (Site Doc, 2022)

From the results of the Borlog Test conducted by the planning and supervision unit of East Nusa Tenggara province (2021) the N-SPT at a depth of 2 m is 20 and continues to increase to a depth of 15 m the value of N-SPT > 60, this indicates that the soil is classified as very stiff-hard (Terzaghi & Peck, 1967). However, after testing in the laboratory as seen by soil investigation at STA 149+140 Motoain-Henes-Motomasin National Road, it shows that the soil is dominated by cohesive soil where % silt and % clay range between 60% -93%. The test

also shows that Bobonaro clay has an LL value $> 60\%$ and a PI value $> 40\%$ from 2 m to 15 m depth. So this can also be one of the causes of cracks along the Motoain-Henes-Motomasin National Road. Cracks that develop in the soil can create a weakened zone within the soil mass, leading to a reduction in its physical strength, mechanical behavior, and overall stability. The presence of cracks on subgrades or road slopes can accelerate saturation due to rainfall infiltration or fluctuations in groundwater levels (Hotineanu et al., 2014). Indonesia, as a tropical country, experiences two main seasons: the rainy season and the dry season. During the rainy season, the soil becomes saturated, while in the dry season, the opposite occurs. Repeated wetting and drying cycles significantly affect the soil's physical and mechanical properties. These effects include changes in soil moisture content, variations in shear stress, alterations in negative pore water pressure, and shifts in soil volume. Such phenomena are commonly found in both residual and sedimentary soils (Goh et al., 2014).

Quicklime (CaO) is produced by calcining limestone, resulting in calcium or magnesium oxides. The most suitable types of lime for soil stabilization are calcium hydroxide ($\text{Ca}(\text{OH})_2$) and calcium oxide (CaO) (Rokman, 2015). Additionally, Firmansyah et al. (2021) state that soil stabilized with 7% $\text{Ca}(\text{OH})_2$ effectively reduces cracking from the initial drying phase to the air-dry condition. The drying phase refers to the reduction of water content within the soil pores, which influences both its physical and mechanical properties. The upper limit of soil moisture is determined from the saturation condition obtained in the Proctor test, while the lower limit corresponds to the air-dry state (Firmansyah et al., 2021).

This research is very important to do to know the effect of the drying process on the cracks of Bobonaro clay and the handling of the subgrade or the edge of the subgrade on the Motoain-Henes-Motomasin National Road by chemical treated using $\text{Ca}(\text{OH})_2$ Lime to reduce cracks that occur.

Research Purposes

1. To evaluate Crack Intesity Factor (CIF) values due to the drying process in natural Bobonaro clay, compacted conditions, and the soil treated with $\text{Ca}(\text{OH})_2$ Lime conditions at laboratory scale.
2. To determine the optimum mixture of lime $\text{Ca}(\text{OH})_2$ and Bobonaro clay using the standard proctor test.

RESEARCH METHOD

The method used in this research is laboratory research, which includes soil investigation testing followed by a proctor test to determine the optimum soil + $\text{Ca}(\text{OH})_2$ Lime mixture. The second method used in this study is to model the samples to be tested for Crack Intesity Factor (CIF). the sample to be tested is modeled as:

1. Initial bobonaro clay conditions.
2. compacted Bobonaro clay conditions.
3. Soil treated with $\text{Ca}(\text{OH})_2$ lime conditions.

Then the drying process will be carried out on the samples in each condition, and CIF testing will be carried out and tests starting from the initial conditions, drying conditions 25%, 50%, 75%, and samples at 100% air dry conditions as shown in Figure 3.

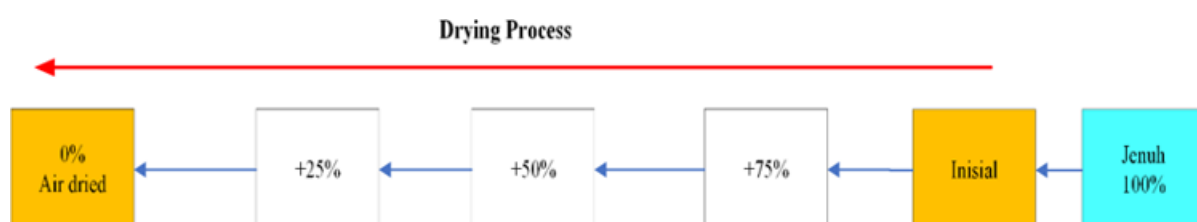


Figure 3. Drying Cycle

DATA COLLECTION

The first primary data used in this research was obtained by taking disturbed and undisturbed soil samples on the Motoain-Henes-Motomasin National Road section. Samples were taken from the subgrade and road shoulder at Sta 149+140 with a depth of 0.5-1 m, then tested the Crack Intesity Factor (CIF) and tested the physical properties due to the drying process on the specimens with 3 conditions, namely initial bobonaro clay conditions, compacted Bobonaro clay conditions, and soil treated with Ca(OH)_2 lime conditions.

The secondary data used in this study were obtained from Satker P2JN East Nusa Tenggara Province, BPJN East Nusa Tenggara. Secondary data includes N-SPT data, soil investigation data, and DED (Detail Engineering Design).

RESEARCH ANALYSIS

1. Data Soil Properties

According to the findings obtained from soil property tests conducted at Sta 149+140 at a depth of 0.5-1 m, The soil is classified as high-plasticity clay (CH) according to the USCS system and falls under the A-7-6 category based on the AASHTO classification. The results of testing soil properties can be seen in Table 1 below.

Table 1a. Initial soil testing results of Bobonaro Clay

No	Laboratory Test	Unit	Initial Result
1	Soil Physical Properties Test		
a	Grainsize		
	Gravel Faction	%	0.00
	Sand Faction	%	2.13
	Silt Faction	%	42.44
	Clay Faction	%	55.43
b	Consistency		
	Liquid Limit (LL)	%	80.83
	Plastic Limit (PL)	%	22.08
	Plasticity Index (PI)	%	58.75
	Shrinkage Limit (SL)	%	17.56
c	Volumetric-Gravimetric		

Table 1b. Initial soil testing results of Bobonaro Clay

No	Laboratory Test	Unit	Initial Result
	Water Content (w_c)	%	19.76927
	Specific Gravity (G_s)		2.598438
	Dry Unit Weight	gr/ cm ³	1.631031
	Void Ratio		0.593183
	Porosity	%	37.23
2 Soil Classification			
	USCS		CH
	AAHSTO		A-7-6
3	Activity		1.06
4 Soil Mechanical Properties Test			
	Unconfined Compression Strength		
	ultimate compressive strength (q_u)	kg/cm ²	1.321572
	Cohesion (C_u)	kg/cm ²	0.66
	Standard Proctor		
	(γ_d) max	(gr/cm ³)	1.70101
	(w_c) Optimum	%	17.00

source: Laboratory test (Author's Data), 2022

Based on Table 4.1 the results of soil investigation at STA 149+140 on the Motoain-Henes-Motomasin National Road, show that the soil is dominated by cohesive soil where % silt and % clay is 97%. It can also be seen in Table 4.1 that soil has a liquid limit value of 80.83% and PI value of 58.75%. So, this is one of the causes of cracks along the Motoain-Henes-Motomasin National Road.

2. Results from the Standard Proctor Test

From Figure 4, it is shown that the Standard Proctor compaction test was conducted on the original Bobonaro clay and on three different test specimens with lime Ca(OH)_2 additions of 4%, 7%, and 10%. The results indicate that soil mixed with Ca(OH)_2 exhibited a higher maximum dry density (γ_d) compared to the untreated Bobonaro clay. The 7% lime-treated soil achieved the highest maximum dry density (γ_d) of 1.825 g/cm³ with an optimum moisture content (w_c) of 20.31%. However, further increasing the lime content beyond 7% resulted in a reduction of the maximum dry density (γ_d). The comparison of Proctor test results for untreated and lime-treated soils is illustrated in Figure 4.

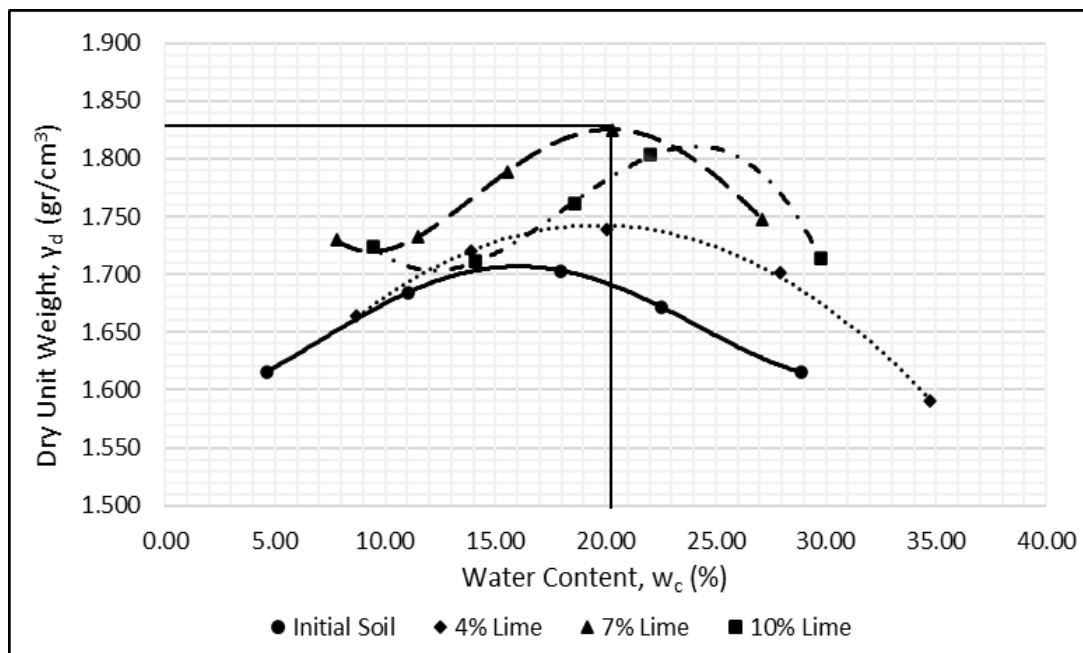


Figure 4. Proctor test results for initial Bobonaro clay and soil treated with Ca(OH)_2 lime of 4%, 7% and 10%

Rokman (2015) states that the most effective types of lime for soil stabilization are calcium hydroxide [Ca(OH)_2] and calcium oxide (CaO). Supporting this, Harnaeni (2013) demonstrated that adding Ca(OH)_2 to clay soils can lower the plasticity index (PI) while enhancing shear strength, cohesion, and the maximum dry density as shown by Proctor test results.

Furthermore, Firmansyah (2021) stated that treating soil with 7% lime effectively reduces cracking starting from the seventh stage of the drying process, or when the drying reaches around 60%. The study also showed that soil stabilized with 7% Ca(OH)_2 lime achieved an increased maximum dry density (γ_d) of 1.47 gr/cm^3 and an optimum moisture content (w) of 28.08%.

3. Crack Intesity Factor (CIF) Analysis

In observing macro-scale soil fractures, a digital camera was used to test the specimens for initial conditions, compacted conditions, and treated conditions with lime and later these data were used in Crack Intesity Factor (CIF) analysis using the Matlab 2019a software. The results of observations of the cracks of the test objects with the drying process to the air-dried condition are as follows:

a. Cracks In Initial Conditions with The Drying Process

Based on the observations in Figure 5 below, In its initial condition, the soil began to develop cracks from the very first phase of the drying process and the cracks began to be clearly visible starting from the 50% drying phase (Figure 5.c). Typical cracks that occur are in the edge area and also in the middle area of the sample and also tend to shrink. The photos are taken every time the water content changes by 25% to 100% air dried conditions.

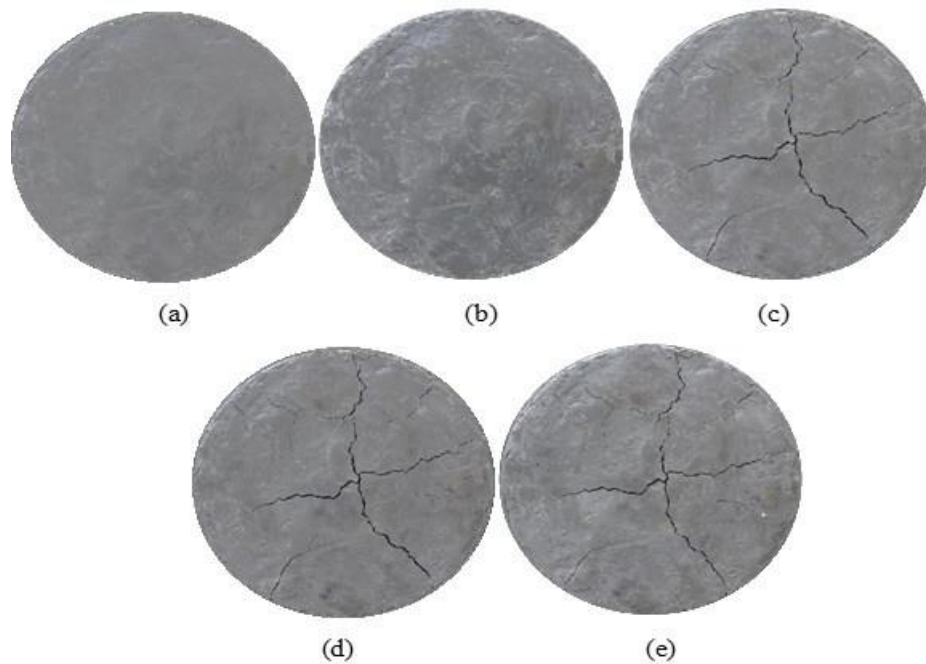


Figure 5. Macro-scale photo of the initial soil with conditions (a) Initial; (b) Drying 25%; (c) Drying 50%; (d) Drying 75%; (e) Drying 100% airdried

The results of running photos in the MATLAB 2019a program in Figure 6 show that the initial soil condition was detected as cracks by the program from the initial phase of the drying process, until near the end of the drying phase or the air-dried condition. It can be seen that the detected cracks are increasing and are almost evenly distributed throughout all parts of the test object.

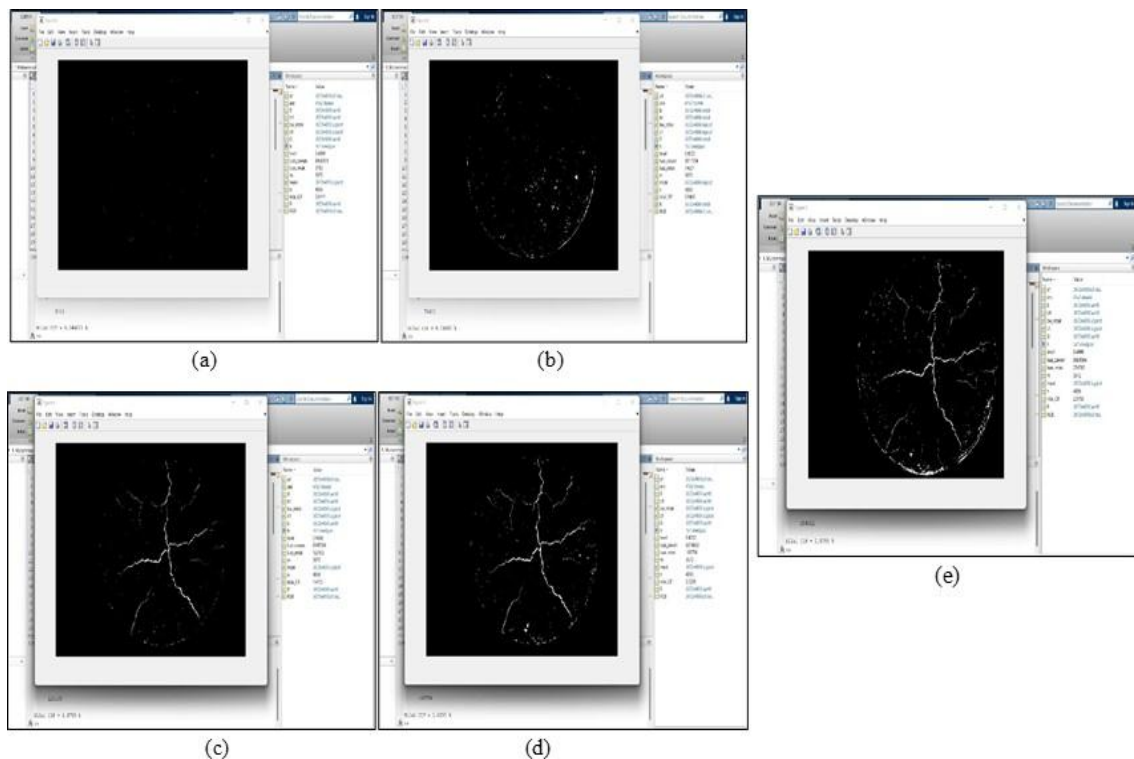


Figure 6. Result of running matlab 2019a of the initial soil with conditions (a) Initial; (b) Drying 25%; (c) Drying 50%; (d) Drying 75%; (e) Drying 100% air-dried

b. Cracks In Compacted Conditions with The Drying Process

Based on the observations in Figure 7 below, the soil for compact conditions also has cracks, but these cracks appear to be fewer than the initial conditions and tend to appear only starting from the 50% drying phase (Figure 7.c). Typical cracks that occur are at the edges and then propagate to the center of the sample and tend to get smaller.

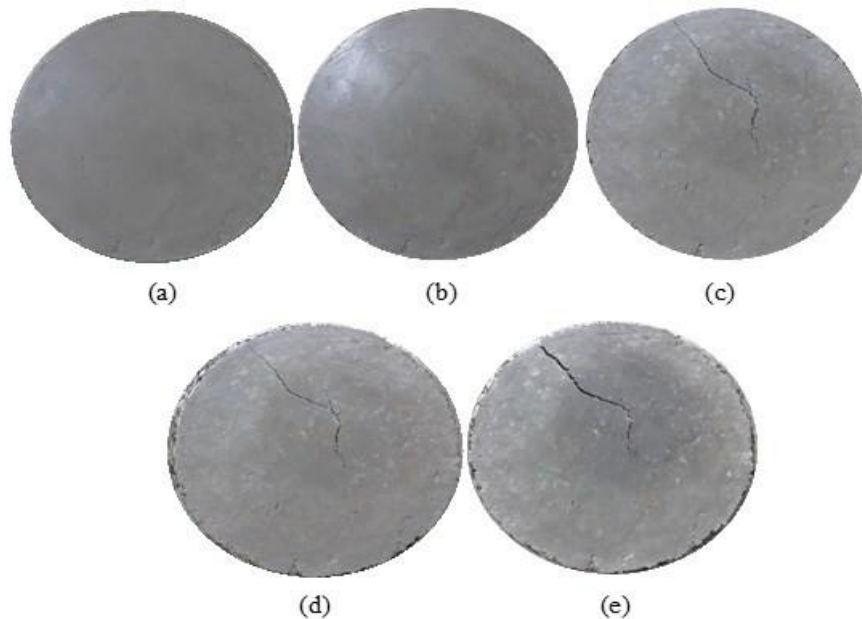


Figure 7. Macro-scale photo of the compacted soil with conditions (a) Initial; (b) Drying 25%; (c) Drying 50%; (d) Drying 75%; (e) Drying 100% air-dried.

The results of the running photos in the MATLAB 2019a program in Figure 8 show that the compacted soil conditions detected cracks by the program since the initial phase of the drying process, but the cracks only started to become apparent at the 50% drying phase. There is 1 area of cracks that extends from the edge to the center of the specimen but not as many as the initial soil conditions.

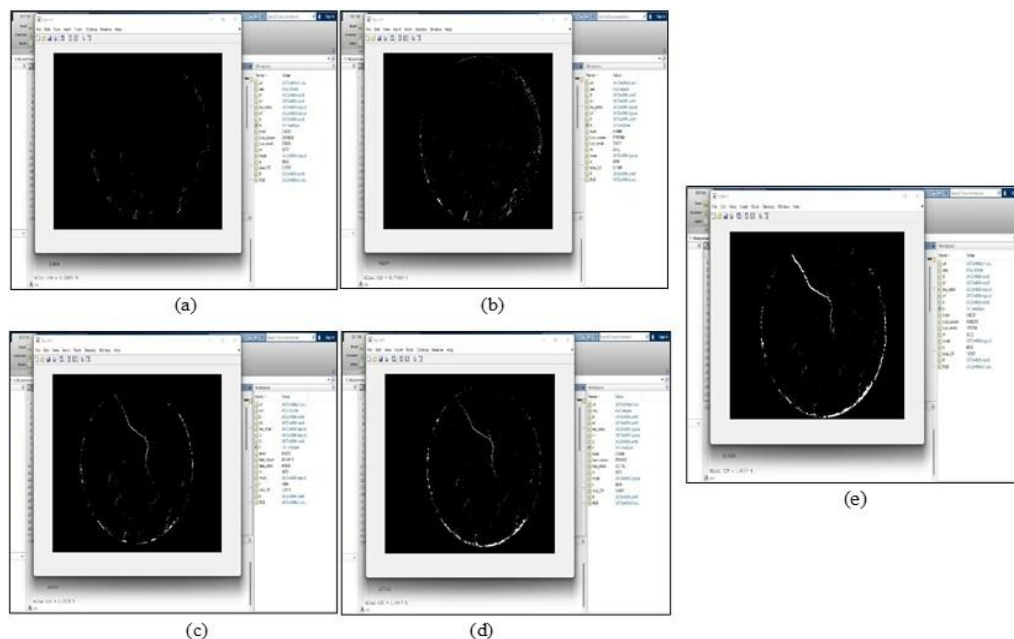


Figure 8. Result of running matlab 2019a of the compacted soil with conditions (a) Initial; (b) Drying 25%; (c) Drying 50%; (d) Drying 75%; (e) Drying 100% air-dried.

c. Cracks In soil treated with 7% $\text{Ca}(\text{OH})_2$ Lime Conditions with The Drying Process

Based on the observations in Figure 9 below, the soil treated with 7% $\text{Ca}(\text{OH})_2$ lime conditions, the cracks that occur tend to be small and not significant when compared to the initial conditions and compacted conditions. cracks occur only in the form of small cracks and typical cracks that occur are only at the edge of the sample and shrinkage occurs (Figure 9.d and Figure 9.e).

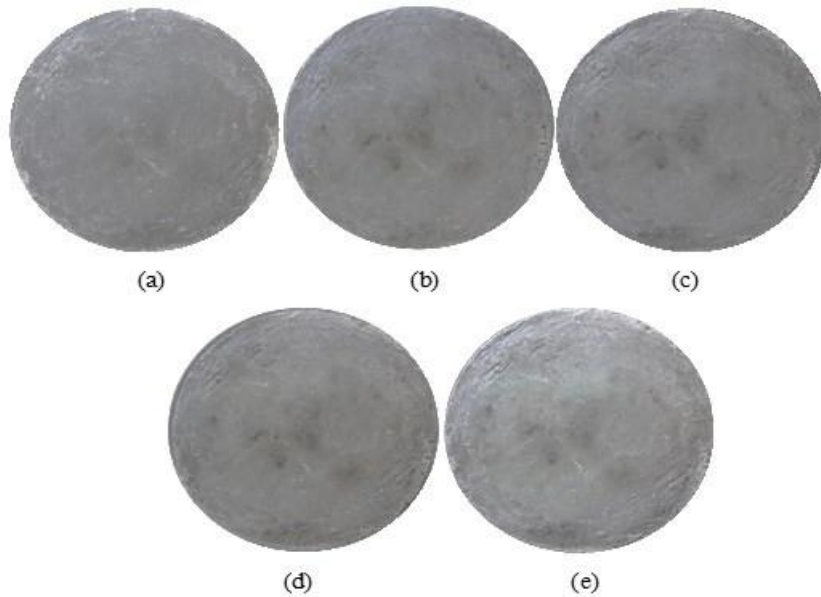


Figure 9. Macro-scale photo of the soil treated with 7% lime conditions (a) Initial; (b) Drying 25%; (c) Drying 50%; (d) Drying 75%; (e) Drying 100% air-dried.

The results of the running photo in the MATLAB 2019a program in Figure 10 show that the soil condition is stable with 7% $\text{Ca}(\text{OH})_2$ lime, only a few cracks were detected by the program from the initial stages of the drying process until the drying process ends or air-dry conditions. The detected cracks are only small and not significant, and most of them are visible at the edge of the test object.

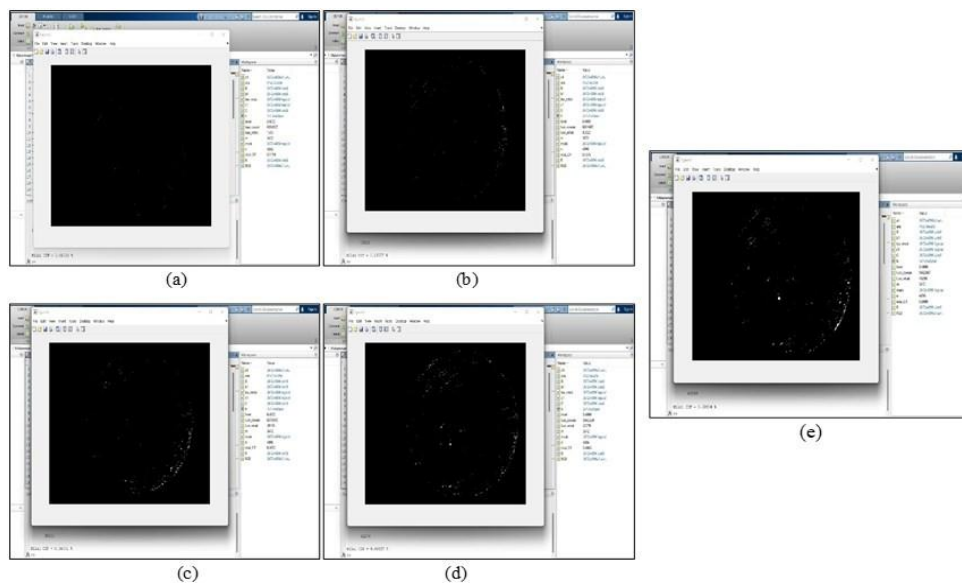


Figure 10. Macro-scale photo of the soil treated with 7% lime conditions (a) Initial; (b) Drying 25%; (c) Drying 50%; (d) Drying 75%; (e) Drying 100% air-dried.

d. Crack Intesity Factor (CIF) value

As shown in Figure 11, soil treated with 7% Ca(OH)_2 lime proved highly effective in minimizing surface cracking. This is evident from the beginning to the end of the drying process, where it displayed the flattest trend line compared to other conditions. The soil stabilized with 7% Ca(OH)_2 lime recorded the lowest Crack Intesity Factor (CIF) value among all variations. At the end of the drying phase, the CIF value for this treatment was 0,5090%. Compacted soil conditions are also able to reduce the number of cracks in the surface soil. This can be seen at the end of the drying process that with maximum compaction in accordance with the proctor test it has a CIF value of 1,8787% which is still lower than the CIF value for initial soil conditions. Where the CIF value at the end of the drying process for the initial soil conditions is 2,5755%. For more details, the graph of the relationship between the value of Crack Intesity Factor (CIF) and the drying process can be seen in Figure 11 below.

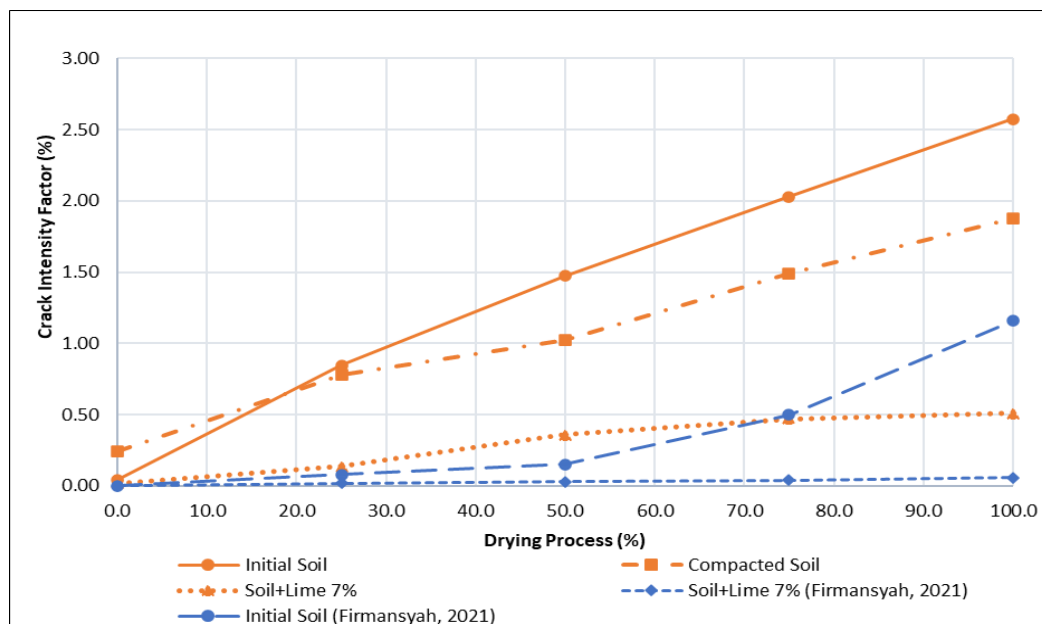


Figure 11. The relationship between the value of Crack Intesity Factor (CIF) and the drying process

According to Firmansyah (2021), soil stabilized with 7% lime shows a flat CIF trend line from the start to the end of the drying process. By the end of the drying phase, the CIF value for soil treated with 7% lime was only 0.06%, compared to 1.16% for the untreated soil. Additionally, the crack width in soil treated with 7% lime remained relatively constant with minimal changes, reaching just 0.25 mm at the end of the drying process.

The percentage of water content during drying and a detailed summary of the test results are presented in Table 2.

Table 2a. Recapitulation of test results

Drying Process (%)		Initial	75	50	25	0
Initial conditions	W_c (%)	19.769	17.856	12.884	7.912	2.939
	CIF (%)	0.0447	0.8460	1.4755	2.0295	2.5755
Compacted Conditions	W_c (%)	17.004	16.395	11.933	7.471	3.009
	CIF (%)	0.2395	0.7789	1.0215	1.4917	1.8787

Table 2b. Recapitulation of test results

Drying Process (%)		Initial	75	50	25	0
Soil+Lime 7%	W _c (%)	20.309	16.277	12.180	8.083	3.987
Conditions	CIF (%)	0.0174	0.1376	0.3600	0.4663	0.5090

CONCLUSION

Based on the evaluation results of soil cracking behavior or the value of crack intensity factor (CIF) due to the drying cycle and the results of data processing, the following conclusions are obtained:

1. Bobonaro clay treated with 7% Ca(OH)₂ lime shows the most stable CIF trend throughout the drying period. From the start to the end of drying, the crack intensity factor (CIF) for the 7% lime-treated soil recorded the lowest final value compared to both untreated Bobonaro clay and compacted soil. At the end of the drying process, the CIF for the lime-treated soil was 0.5090%, whereas compacted soil reached 1.8787%, still lower than the initial untreated Bobonaro clay, which had the highest CIF of 2.5755%.
2. The standard Proctor test for the original Bobonaro clay, sourced from the Motoain–Henes–Motomasin National Road Section in East Nusa Tenggara Province, showed a maximum dry unit weight (γ_d) of 1.7101 gr/cm³ with an optimum moisture content (w_c) of 17.00%. When the soil was treated with 7% Ca(OH)₂ lime, the maximum dry unit weight (γ_d) increased to 1.825 gr/cm³, while the optimum moisture content (w_c) rose to 20.31%, proving the improvement in compaction characteristics with lime stabilization.
3. From the above points it can be concluded that soil treatment with Ca(OH)₂ lime is effective in reducing cracks in Bobonaro clay.

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