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Effect of Stabilization Soil With Fly Ash and Bottom Ash on Characteristics of Residual Soil (Padang-Sicincin Toll Road)

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ABSTRACT

Utilization of residual soil in the Trans Sumatra Toll Road Construction Project Padang - Sicincin Section found residual soil types at Sta. 27+000 - 27 + 400 as road embankment and subgrade can be done by stabilization method where the stabilization material used is a mixture of fly ash, bottom ash, and FABA (fly ash+bottom ash). To obtain the optimum percentage of Fly ash, Bottom ash, or FABA (Fly ash Bottom ash) in improving soil behavior, the variations are 10%, 15%, and 20% of bulk density with an incubation period of 0 days, 7 days and 14 days will be selected.

Based on the analysis, it is found that stabilization (fly ash, bottom ash, or FABA) results in changes in physical and mechanical residual soil properties with an increase in the CBR value in addition to fly ash at 10% with a CBR value = 4.02%, bottom ash at 20% with a CBR value = 9.49% and FABA at 20% with a CBR value = 14.32% so that the stabilized soil can be used as ordinary backfill soil or preferred backfill soil.

Keywords : Soil stabilization, residual soil, fly ash, bottom ash, FABA

INTRODUCTION

Roads are one of the country's infrastructure assets that must be managed because they can connect the economy of an area with other areas to improve the standard of living and development of an area. According to (Suprayitno & Soemitro, 2018), infrastructure asset management is the science, knowledge, or program for managing infrastructure so that it can perform its functions sustainably, effectively, and efficiently. Therefore, roads must be built and managed using the principles of infrastructure asset management. The Trans-Sumatra Toll Road, spanning 2,818 kilometers, is a planned toll road network in Indonesia designed to link cities across the island of Sumatra, extending from Lampung to Aceh. Planning the construction of this road often passes through locations of problematic soils. Problematic soil is one of the important factors that cause the decline or disruption of the stability of constructions such as roads and bridges. The soil in road construction functions as a subgrade that supports the construction load and traffic above it. This was found in toll road construction in West Sumatra, in particular at Sta. 27+000 - 27 + 400 Padang - Sicincin Toll Road Construction Project which has contours of hills and mountains **Figure 1.** So that a lot of cutting or dredging of native soil is carried out at that location. Even some locations require high embankment to achieve the planned elevation conditions.

Figure 1. Existing Soil Condition at Sta. 27+000 - 27 + 400
(Documentation of Padang - Sicincin Toll Road Construction Project)

It was found that the soil at the site was residual soil that was highly inadequate for use as fill, either as regular fill or preferred fill. Based on laboratory testing, the soil did not meet specifications. From physical and mechanical testing results of the soil at the site, it was found that the CBR value was <6% for ordinary fill. Considering the plasticity index value (PI) and the liquid limit (LL) in **Table 1.** it can be concluded that the soil in the Padang - Sicincin Toll Road Construction Project Sta. 27+000 - 27+400 has a high degree of development based on PI value and very high based on LL value according to the characterization of expansive degree by Costet and Sanglerat (1981). According to USCS, soil is included in the type of soil with high plasticity silt (MH). Then the soil activity analysis as defined by Skempton (1953) concluded that the level of soil activity was classified as inactive.

Table 1. Summary of Laboratory Soil Test Results Sta. 27+000 - 27 + 400

No.	**Description**		**Unit**	**Value**
				Data
1	Bulk Density (γt)		Gr/cm³	1.287
2	Water Content		%	35.50
3	Atterberg Limit			
	a. Liquid Limit (LL)		%	65.39
	b. Plastic Limit (PL)		%	42.87
	c. Plastic Index (PI)		%	22.53
5	Specific Gravity			2.518
6	Void Ratio			
7	Sieve Analysis		Pass	
	(mm)	(Inchi)		
	4.76	#4	%	100
	2.00	#10	%	92.65
	0.42	#40	%	78.91
	0.149	#100	%	71.61
	0.074	#200	%	67.56
8	Soil Specifications	AASHTO		A-7-5
		USCS		OH/MH

Source: Padang - Sicincin Toll Road Construction Project

At the time of observation in the field when compaction work was carried out, the soil released excess water, so it was feared that there would be indirect compression later if construction work was carried out. The handling carried out in the field is to remove residual soil with a thickness of 2 - 3 meters which will then be handled using a stone column according to **Figure 2.** Digging up residual soil with a depth of 2 - 3 meters will remove ± 1,000,000 m³ of soil. This underlies the need to utilize the residual soil.

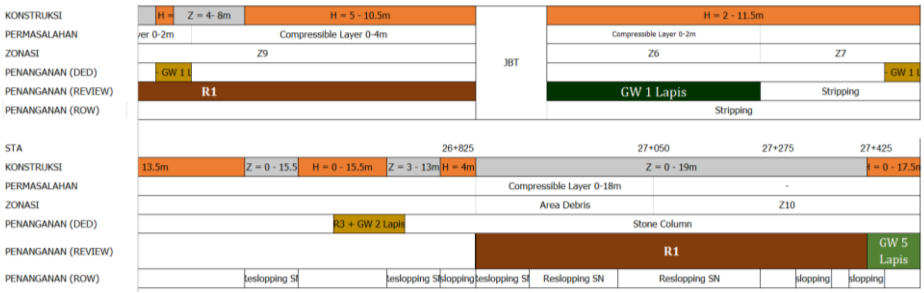
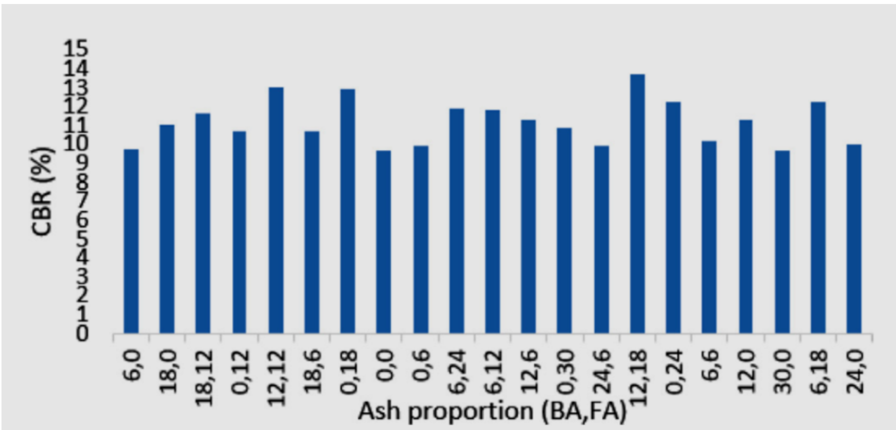


Figure 2. Design of Residual Soil Handling at Sta. 27+000 - 27+400 (Padang - Sicincin Toll Road Construction Project)

For the use of residual soil either as road embankment or as subgrade, it is necessary to stabilize it. Soil stabilization, also known as soil improvement, involves enhancing soil properties by incorporating additional materials or employing mechanical methods to fulfill the criteria for desired soil strength and durability. Along with the development of technology today, there are several ways to improve soil. Some types of soil improvement are by adding geosynthetic, mechanical, and chemical layers. In this study, chemical stabilization was carried out by adding fly ash and bottom ash.



(Sharma & Singh, 2019)

Figure 3. Graph of the Effect of the Addition of Fly ash and Bottom ash Variations

Earlier studies have shown that augmenting soil strength is attainable by introducing a combination of fly ash and bottom ash into the soil. The optimal proportions for enhancing soil strength were determined to be 12% for bottom ash and 18% for fly ash. The total increase in the California Bearing Ratio (CBR) value for the optimum mixture, compared to the initial soil, was documented at 4.02%, marking an improvement from 9.68% to 13.7%. (Sharma & Singh, 2019) that can be seen in **Figure 3** Based on the findings of these studies, it is evident that the stabilization of residual soil involves the incorporation of fly ash, bottom ash, and a combination of both (FABA). This research explores different proportions, specifically 10%, 15%, and 20% of fly ash, bottom ash, and FABA (fly ash + bottom ash) relative to the dry weight of the soil.

In accordance with ASTM C618, fly ash is categorized into two classes: F-class fly ash and C-class fly ash. The primary distinction between these two types of fly ash lies in their respective levels of calcium, silica, aluminum, and iron content. Class C fly ash is characterized by a lime content (CaO) exceeding 10% and possesses pozzolanic and self-cementing properties. This denotes its ability to solidify and enhance strength through a reaction with water without requiring the addition of lime. In contrast, Class F fly ash, with a low lime content (CaO < 10%), exhibits pozzolanic properties. To confer cementitious properties upon Class F fly ash, the addition of hydrated lime, quicklime, or cement is necessary to activate its performance. This is predominantly observed in the stabilization of soil where fly ash is employed as the stabilization material.

There has been no research on stabilization with the addition of Fly ash and Bottom ash in residual soil to increase the soil-bearing capacity. This is the background of the research on the Stabilization of Residual Soil with Fly ash and Bottom ash (FABA) for the Improvement of the Subgrade Layer and Road Embankment on the Padang - Sicincin Toll Road Sta. 27+000 - Sta. 27+400. so that the best mixture variation with the optimum curing incubation period can be obtained. This research is important to obtain a variety of Fly ash, Bottom ash, and FABA (Fly ash Bottom ash) mixtures as well as the optimum curing time that is suitable for the soil on the Padang - Sicincin Toll Road.

LITERATURE REVIEW

Soil always has an important role in soil work as the basic support of a building or the construction material of the building itself. As per Braja (1988), soil is described as a substance comprised of aggregates (grains) of solid minerals that are not chemically bonded or cemented together. It also includes organic materials that have undergone decay (solid particles), along with liquids and gases filling the voids between the solid particles. Additionally, the role of soil extends to providing support for building foundations. So, it is necessary for the soil to withstand the load on it and spread it evenly(Kementerian, 2020).

Soil Classification

The existing soil classification system has several versions, this is because the soil has varied properties. Some of the existing soil classification methods include:

- USDA Soil Classification System

The United States Department of Agriculture (USDA) devised a soil classification system based on texture, which hinges on the size of soil grain boundaries. The categorization is as follows:

a. Sand, grain size diameter 2 - 0.05 mm
b. Silt, with a grain size ranging from 0.05 to 0.002 mm in diameter
c. Clay, grain size < 0.002 mm

- AASHTO Soil Classification System

The classification system, initially established in 1929 as the Public Road Administration Classification System, has undergone modifications over time. The classification system relies on the following criteria:

1. Grain size: Gravel: granules pass through a 75 mm (3 in) diameter sieve and are retained on sieve no. 10 (2 mm) Sand: grains passing through sieve no. 10 (2 mm) and retained on sieve no. 200 (0.075mm) Clay and Silt: soil grains pass through sieve no. 200 (0.075 mm)

2. Plasticity: The name silty is used when the soil has a plasticity index (PI) of 10 or less and the name silty is used when the soil has a PI of 11 or more.
3. If rocks (larger than 75 mm in size) are found in the soil sample, the rocks must be removed first, but the percentage of the rocks removed must be recorded.

- USCS System Soil Classification

Following the Unified Soil Classification System (USCS) as stated by Das (1995), soils are categorized into:

1. Coarse-grained soil comprises gravel and sand, with less than 50% of the total weight of the soil sample passing through sieve no. 200.
2. Fine-grained soil consists of silt and clay, where more than 50% of the total weight of the soil sample passes through sieve no. 200.

Residual Soil

Residual soil is soil formed directly because of chemical weathering that remains in place of the original rock. What distinguishes residual soil from sedimentary soil is the presence of minerals formed from the chemical weathering process. The degree of weathering varies with the depth of the fissures and fractures in the rock will accelerate the weathering process (Soemitro & Warnana, 2020).

The deepest layer of residual soil generally still has the mineral composition and grain orientation of the original rock. The extent of weathering is strongly influenced by factors such as rock type, permeability, and the degree of rock cementation (Meiwa, 2020).

The type of clay minerals produced in a particular situation is highly dependent on the rock of origin and the weathering environment. Some of the factors that influence minerals.

Laboratory Testing

Laboratory testing is conducted to ascertain the soil parameters' values. The parameters obtained are physical properties, mechanical properties, and chemical and mineral elements contained in the soil tested. everal laboratory tests will be conducted on soil samples to assess the physical and mechanical properties of the soil, including:

<u>Physical Properties Testing:</u>

1. Gravimetric Volumetric Testing
2. Atterberg Limit Testing
3. Grain Gradation Testing

<u>Mechanical Properties Testing:</u>

1. Compaction Testing (Standard Proctor)
2. Shear Strength Testing
3. Triaxial Testing
4. CBR (Capacity Bearing Ratio) Testing

Curing or Treatment of Test Objects

Extinguishing or treatment of test specimens is done by storing test specimens in a closed container and keeping them away from direct sunlight. Extinguishing is done in several variations namely 0 days, 7 days, and 14 days. In addition to maintaining the moisture content of the test specimens, this curing aims to provide sufficient time for the stabilizers to react with the soil and produce the best stabilization characteristics so that the optimum treatment time in residual soil stabilization using fly ash and bottom ash is known.

Making Variations of Test Objects

Test specimens were made with three categories as follows:

1. Soil + fly ash
2. Soil + bottom ash
3. Soil + FABA

RESEARCH METHODS

The research method used is based on collecting secondary data and primary data as follows:

1. Literatures Study
2. The literature review focuses on the attributes of residual soil and the process of soil stabilization utilizing fly ash and bottom ash.
3. Secondary data collection in the field.
4. The required field data collection includes location data used, basic soil properties including data from laboratory and field tests, soil stratigraphy data, and DED.
5. Evaluation of the physical and mechanical characteristics of residual soil.
6. Evaluation of the physical and mechanical characteristics of residual soil treated with fly ash and bottom ash.

RESEARCH ANALYSIS

Physical and Mechanical Properties Testing of Residual Soil

Testing of residual soil properties is carried out in the laboratory with test parameters in the form of physical properties and mechanical properties. The examined physical properties of the residual soil included water content (WC), specific gravity (Gs), void ratio, and Atterberg limits (PI). The mechanical properties assessed for the residual soil involved triaxial testing, Proctor test, and California Bearing Ratio (CBR). Laboratory tests were carried out using ASTM-1984.

a. Physical Properties of Residual Soil

The residual soil test results of sta 27+125 initially compared with secondary soil data at the same location are given in **Table 2.**

Table 2a. Comparison of residual soil physical properties from secondary data with primary laboratory testing

No.	Description		Unit	Value	
				Secondary Data	Laboratory Testing
1	Bulk Density (γt)		Gr/cm³	1.287	1.664
2	Water Content		%	35.50	31.43
3	Atterberg Limit				
	a. Liquid Limit (LL)		%	65.39	45.18
	b. Plastic Limit (PL)		%	42.87	30.73
	c. Plastic Index (PI)		%	22.53	14.45
5	Specific Gravity			2.518	2.658
6	Void Ratio				1.231
7	Sieve Analysis		Pass		
	(mm)	(Inchi)			
	4.76	#4	%	100	100
	2.00	#10	%	92.65	98.94
	0.42	#40	%	78.91	86.82

Table 2b. Comparison of residual soil physical properties from secondary data with primary laboratory testing

No.	Description		Unit	Value	
				Secondary Data	**Laboratory Testing**
	0.149	#100	%	71.61	66.435
	0.074	#200	%	67.56	53.815
8	Soil Specifications	AASHTO		A-7-5	A-7-6
		USCS		OH/MH	OL/ML

Source: Secondary Data 2022 and Primary Data 2023

From **Table 2.** It can be concluded that the remaining soil is included in the fine-grained sandy soil classification A-7-6 (AASHTO) and has a PI value of <17% so it is included in soil with low plasticity.

b. Mechanical Properties of Residual Soil

The results of the residual soil testing at Sta 27+125 initially compared with the secondary data of the soil at the same location are given in **Table 3.**

Table 3. Comparison of residual soil mechanical properties from secondary data with primary laboratory testing

No.	Description	Unit	Value		Specification
			Secondary Data	**Secondary Data**	
1	California Bearing Ratio (CBR)		5.85	0.35	min. 6%
2	Cohesion (C)	kPa	0.066	0.288	
3	The angle of internal friction (φ)	^{0}	32.36	36.3	

Source: Secondary Data 2022 and Primary Data 2023

From **Table 3** With a California Bearing Ratio (CBR) value below 6%, the residual soil is categorized as soft soil according to (Kementerian, 2020) Based on the soil's consistency and the Angle of Internal Friction (Ø) value (Braja, 1988), the residual soil exhibits an Angle of Internal Friction (Ø) of 36.3^0 , classifying it as a type of dense sand soi.

Chemical Content of Stabilization Materials

The fly ash and bottom ash used come from incineration waste from the Pacitan Steam Power Plant (PLTU), East Java. Chemical content testing was carried out by the Sucofindo Surabaya Laboratory using the XRF method. The results of the chemical content analysis can be seen in **Table 4** The dominant element in the test object is the element Si (silica) with a composition of 38.81%. Meanwhile, Fe is only 14.62%. When compared with the results that have been used by other researchers regarding soil stabilization, the content of several elements such as silica, aluminum (Al), iron (Fe), calcium (Ca), potassium (K), and titan (Ti) is still within the existing value range. as in the bar chart in **Figure 4.**

Table 4. Fly ash Chemical Composition

No.	Parameter	Unit	Value Test	Method
1	SiO_2 (*Silicon Dioxide*)	% wt	32.73	ASTM D4326 - 21
2	Al_2O_3 (*Aluminium Oxide)*	% wt	13.81	
3	Fe_2O_3 (*Iron Trioxide*)	% wt	13.53	
4	CaO (*Calcium Oxide*)	% wt	21.92	
5	MgO (*Magnesium Oxide*)	% wt	8.7	
6	Na_2O (*Sodium Oxide*)	% wt	1.21	
7	K_2O (*Potassium Oxide*)	% wt	0.82	
8	TiO_2 (*Titanium Oxide*)	% wt	0.64	
9	Loss On Ignition (LOI)	% wt	4.08	ASTM D7348 - 13

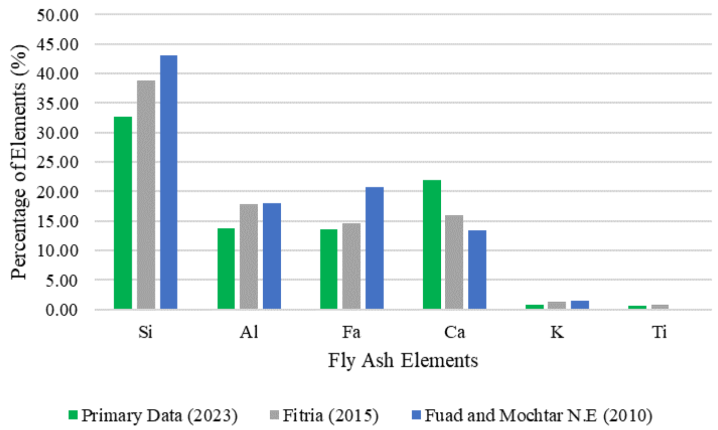


Figure 4. Range of fly ash with previous researchers

Based on ASTM C618-03 fly ash is classified into two classes, namely classes F and C. From the test results listed in **Table 4**, the determination of fly ash class according to ASTM C 618-03 is:

1. $SiO_2 + Al_2O_3 + Fe_2O_3 = 60.07\% < 70\%$ hence type C fly ash.
2. $SO_3 = 1.78\% < 5\%$ hence type F fly ash.
3. CaO = 21.92% > 10% hence fly ash type C.

From these results, the fly ash used in this research is included in class C because of the 2 requirements above. Fly ash meets the class C category which has a high CaO content, namely around 21.92%. From laboratory results, the specific gravity of fly ash is 2.25 t/m^3.

Another stabilizing agent is bottom ash, a byproduct generated from the coal combustion process, manifested as coarse material settling at the furnace's bottom. Its origin aligns with the source of the fly ash utilized in this study, both stemming from the waste produced during the combustion of the Pacitan PLTU. Power Plant (PLTU), East Java. This stabilizer is also tested for its chemical content to find out what percentage of CaO (calcium oxide) is contained in the lime that will be used as a stabilizer. The results of chemical tests using the XRF method can be seen in **Table 5**. From **Table 5** the value of CaO content is the largest compared to the value of other elements so that the Ca element contained in bottom ash can react with the Si element contained in fly ash perfectly.

Table 5. Bottom ash Chemical Composition

No.	Parameter	Unit	Value Test	Method
1	SiO_2 (*Silicon Dioxide*)	% wt	39.15	ASTM D4326 - 21
2	Al_2O_3 (*Aluminium Oxide)*	% wt	7.97	
3	Fe_2O_3 (*Iron Trioxide*)	% wt	17.30	
4	CaO (*Calcium Oxide*)	% wt	9.60	
5	MgO (*Magnesium Oxide*)	% wt	4.79	
6	Na_2O (*Sodium Oxide*)	% wt	0.56	
7	K_2O (*Potassium Oxide*)	% wt	0.44	
8	TiO_2 (*Titanium Oxide*)	% wt	0.41	
13	Loss On Ignition (LOI)	% wt	17.66	ASTM D7348 - 13

Source: Primary Data, 2023

Physical Properties of Stabilized Residual Soil

Testing of the physical properties of residual soil stabilized under optimum conditions in a mixture of 10% FA, 20% BA, and 20% FABA stabilizer includes water content (WC), soil volume weight (γt), and specific gravity (Gs). The mechanical properties tested are CBR and Triaxial Testing. Mixture testing was carried out on days 0, 7, and 14 days.

1. **Water Content (Wc)**

The relationship curve between moisture content and Fly ash, Bottom ash, and FABA stabilizers in each mixture of 10%, 15%, and 20% can be seen in **Figure 5.** The greater the percentage of stabilizer, the lower the water content. The effect of curing age also influences changes in water content values. This condition of decreasing water content is caused by the more stabilizer added, the more water in the pores which is used to react with the stabilizer to form $CaSiO_3$ gel.

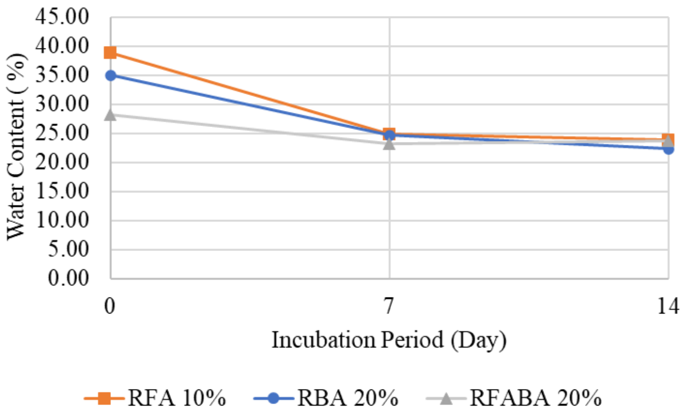


Figure 5. Relationship Graph of Moisture Content and Holding Incubation Period with Stabilization Of FA 10%, BA 20% And FABA 20%. (Source: Primary Data, 2023)

From the curves above, the composition of the stabilizer and the stabilization of the initial soil (water filtration) also affect the residual soil moisture content. The initial moisture content of 53.35% decreased after stabilization.

2. Bulk Density (γt)

The density of the soil after stabilization is getting bigger and increasing as the days of curing increase. This shows that the more stabilized material that reacts, the more gel is formed and fills the pores, making the soil denser. This is due to the tendency of the water content to decrease for a longer curing incubation period, which means that the less water content, the larger the solid soil grains. The denser the remaining soil, the greater the volume weight as seen in **Figure 6** below.

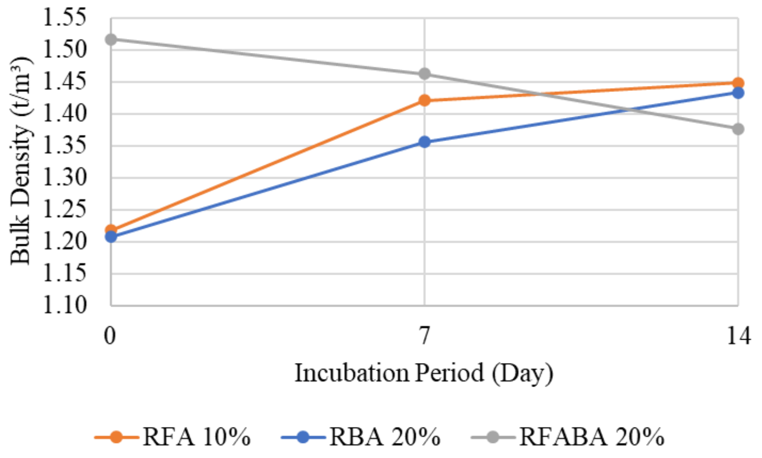


Figure 6. Graph of Volume Weight Versus Incubation Period with FA 10%, BA 20%, and FABA Stabilization 20%. (Source: Primary Data, 2023)

From the graph above, the age of stabilization (curing) affects the volume weight. The longer the age of curing, the more the volume weight increases. In Figure 4.12, namely the addition of 20% FABA stabilizer for the age of 0 - 7 days, the volume weight is greater than the addition of 10% FA stabilizer and 20% BA which tends to be the same. The volume weight has increased because the silica gel has filled the pores in the soil and then crystallized so that it can bind the peat soil well. However, at the age of 14 days, it can be seen that the volume weight value of the addition of 20% FABA stabilizer has decreased due to the possibility of uneven mixing of stabilization materials and also the influence of water filtration from unstabilized soil, the possibility of groundwater added to the unstabilized soil area cannot be absorbed by the soil so that more water filtration enters the stabilized area which causes the soil and stabilizer material cannot form a gel properly (Purnama & Ridwan, 2018). But in the addition of 20% FABA stabilizer, the value is greater than the addition of 10% FA and 20% BA stabilizers at 0 - 7 days, so there is an effect of soil grading diversity for volume weight values.

A. Specific Gravity (Gs)

In **Figure 7** as the age of soaking increases, it decreases in all variations. he reduction in the Specific Gravity (Gs) value of the treated soil is attributed to a process of agglomeration or clumping within the soil. This causes the volume of the granules to become larger.

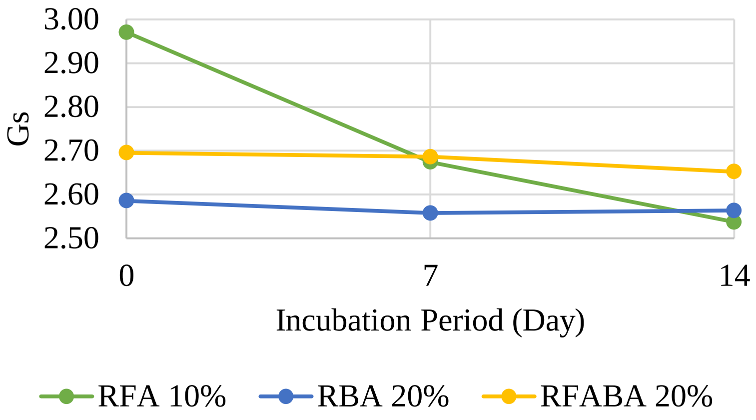


Figure 7. Graph of Gs Value Versus Incubation Period with Stabilization Variations Of FA 10%, BA 20% And FABA 20%. (Source: Primary Data, 2023)

B. Void Ratio

The addition of stabilizing material to the remaining soil causes the pore number value to be much smaller than the pore number value for the unstable remaining soil. The gels formed due to the reaction of the stabilizing agent fill the pores of the peat which causes the pore cavity to be more closed and makes the soil denser. **Figure 8** Illustrates the impact of the curing and stabilization mixture on each optimal variation.

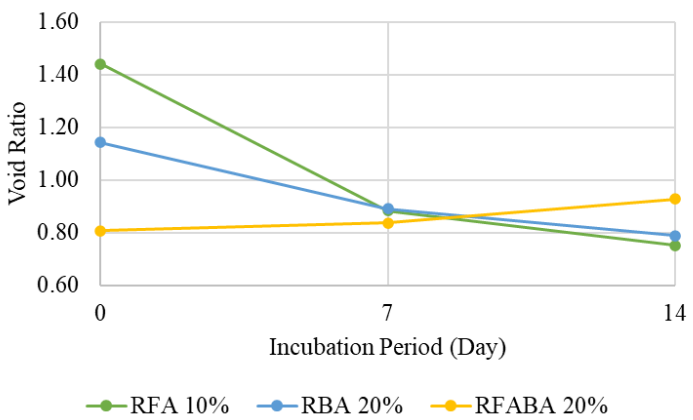


Figure 8. Graph of void ratio Versus incubation period with 10% FA, 20% BA, and 20% FABA stabilizers. (Source: Primary Data, 2023)

The increase in the pore water number in the variation of adding 20% FABA stabilizer is due to the effect of the speed of the gel formation reaction that occurs slowing down so that the filling of pore water slows down compared to the variation of adding 10% FA and 20% BA stabilizers By previous research that fly ash stabilizer material very quickly fills the pores in the soil (Wahyuni, 2016), but in contrast to bottom ash stabilizer material which tends not to be able to fill the soil pores because the size of the material grain gradation is larger than the size of the fly ash material grain gradation.

C. Atteberg limit

To assess the influence of fly ash on soft soil, a soil consistency limit test was conducted. The soil consistency limit is determined through the liquid limit (LL) test and the plastic limit (PL) test. The outcomes of the liquid limit test (LL) indicate a decrease with the incorporation of stabilizer material into the soil. This occurs due to a cementation process facilitated by fly ash and bottom ash, leading to an enlargement of soil grains. Consequently, the attractive force between particles in the soil diminishes (Dwi Wahyuni, 2021). The plastic limit (PL) test tends to decrease which affects the plastic properties of the soil. The decrease in the liquid limit (LL) value affects the plasticity index (PI) value which decreases significantly when the soil is vulcanized. This shows that with the addition of a stabilizer mixed with the remaining soil, the mixed soil tends to be better due to reduced soil plasticity. The results of the stabilized soil consistency limit test are listed in Table 4.10.

Table 6. Test Results of Consistency Limits of Stabilized Soil

	LL (%)	*PL (%)*	*PI (%)*
Residual Soil	65.39	42.87	22.53
RFA-14-10	34.70	29.35	5.35
RBA-7-20	31.57	21.41	10.17
RFABA-14-20	31.27	24.90	6.37

Source : Primary Data, 2023

Mechanical Properties of Stabilized Residual Soil

The mechanical assessment of residual soil involves conducting the standard Proctor test and California Bearing Ratio (CBR) test. After the mechanical testing, the optimum variation for each stabilizer material will be obtained which is then used as the basis for finding the soil parameters.

1. **Standard Proctor Test**

Light soil compaction testing uses SNI standards (SNI-1742-2008, 2008), a method for testing light soil compaction. Light soil compaction test using air-dried SSD soil, soil pass filter no. 4 by adding water content of 5%, 10%, 15%, 25%, and 30% then leaving it for one day/24 hours. The procedure involved adding a percentage of water content to the dry weight of the residual soil. Subsequently, the soil samples were crushed, and individual samples were extracted to ascertain the water content of each crushed sample. From the water content obtained from the formula $\gamma d = \gamma b / (1+w)$ the dry weight of the soil γd can be obtained then the optimum water content and maximum dry weight of the soil can be obtained.

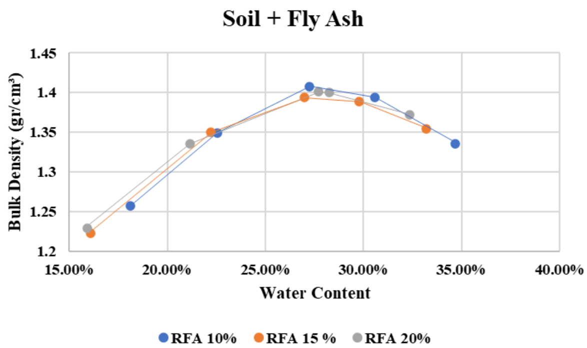


Figure 9. Graph of water content versus dry volume weight in the variation of Fly ash 10%, Fly ash 15%, and Fly ash 20% (Source: Primary Data, 2023)

From **Figure 10**, the value of Fly ash 10% mixture γd Max = 1.410 gr/cm³ and Wopt = 28.13%, Fly ash 15% mixture γd Max = 1.390 gr/cm³ and Wopt = 28.34% and Fly ash 20% mixture γd Max = 1.401 gr/cm³ and Wopt = 28.27%. The optimum value of γd Max in the Fly ash mixture variation was obtained as 1.410 gr/cm³ so that the optimum W can be obtained at 28.13% in the variation of 10% soil + Fly ash mixture.

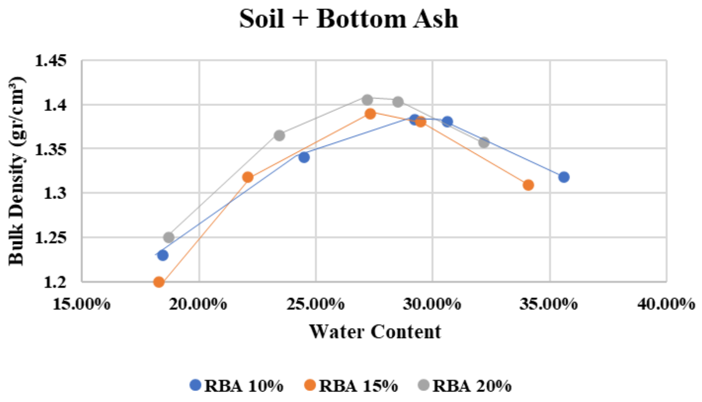


Figure 10. Graph of water content versus dry volume weight in variations of Bottom ash 10%, Bottom ash 15%, and Bottom ash 20% (Source: Primary Data, 2023)

From **Figure 11**, the value of Bottom ash 10% mixture γd Max = 1.380 gr/cm³ and Wopt = 29.27%, Bottom ash 15% mixture γd Max = 1.390 gr/cm³ and Wopt = 28.05% and Bottom ash 20% mixture γd Max = 1.401 gr/cm³ and Wopt = 27.97%. The optimum value of γd Max in the Bottom ash mixture variation was obtained as 1.410 gr/cm³ so that the optimum W can be obtained as 27.97% in soil + Bottom ash 20% mixture variation.

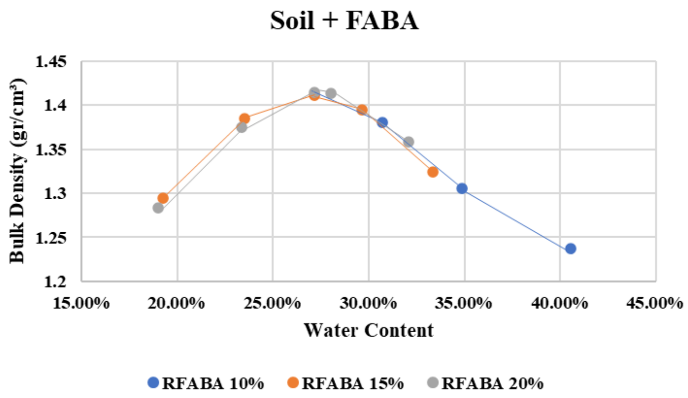


Figure 11. Graph of water content Versus dry volume weight in variations of FABA 10%, FABA 15%, and FABA 20% (Source: Primary Data, 2023)

From **Figure 11**, the value of γd Max = 1.250 gr/cm³ and Wopt = 35.53% for FABA 10% mixture, γd Max = 1.410 gr/cm³ and Wopt = 27.14% for FABA 20% mixture, γd Max = 1.420 gr/cm³ and Wopt = 27.16%. The optimum value of γd Max in the FABA mixture variation was obtained at 1.420 gr/cm³ so that the optimum W can be obtained at 27.16% in the variation of 20% soil + FABA mixture.

Therefore, it can be deduced that the optimal mixture variations consist of 10% fly ash, 20% bottom ash, and 20% fly ash + bottom ash. The percentage of added stabilizer comes from the dry weight of the remaining soil. The optimal water content values obtained from the optimal mixture variations serve as the foundation for preparing soil mixtures with stabilizers for conducting California Bearing Ratio (CBR) laboratory tests.

2. California Bearing Ratio (CBR) Test

Table 7. Laboratory California Bearing Ratio (CBR) Test Results for Each Mixture Variation

CBR Testing	Incubation period (Day)	Initial Soil	Stabilizer		
			Fly ash 10%	Bottom ash 20%	FABA 20%
CBR Value (%)	0	0.35	0.95	1.42	3.28
	7	0.35	2.41	9.49	6.43
	14	0.35	4.02	5.63	14.32
Percentage Increase		0	1049.05%	2611.75%	3990.61%

Source: Primary Data, 2023

From Table 4.7 stabilization with a Fly ash content of 10% with an optimum incubation period of 14 days, a CBR value of 4.02% of the original soil CBR value. In stabilization with a bottom ash content of 20% with an optimum incubation period of 7 days, the CBR value will increase by 2611.75% compared to the CBR value of the original soil. Meanwhile, stabilization with FABA of 20% with an optimum incubation period of 14 days will be able to provide an increase in the CBR value of 3990.61% to the CBR value of the original soil. Based on the Department of Public Works Bina Marga Specification, the original soil CBR test results are 0.35, so this soil is included as soil that does not qualify as backfill and subgrade/foundation soil because the CBR value is less than the required CBR < 6. After stabilization with Bottom ash stabilizer at 20% and FABA at 20%, the remaining soil meets the requirements to be used as a normal landfill, but not with the addition of Fly ash at 10% which has not yet reached the required CBR value. The use of bottom ash and FABA in soil stabilization will result in an increase in the dry weight of the initial soil. The automatic increase in the CBR value is a direct result of augmenting the dry weight of the initial soil. This is because Bottom ash and FABA contain silica and lime which will bind water to the remaining soil so that it reacts with the soil to form $CaSiO_3$ gel and will bind soil grains because there is the element silica whose volume weight is greater than the volume weight of the soil. real soil granules (Wahyuni, 2016), then this silica causes the original soil to bond with a stabilizer, thereby increasing the dry volume. With hydraulic binding in the soil, the soft soil becomes stiff soil and will dry and harden quickly, and the dry volume weight will increase, thus the CBR value will increase, if the CBR increases then the stability of the soil will increase and the CBR value will increase. the soil bearing capacity qu will increase. Stabilization with bottom ash and FABA can increase the CBR value of the soil, the increase that occurs ranges from 1049.05% - 3990.61% of the original soil CBR value.

3. Unconsolidated-Undrained (UU) Triaxial Test

From each optimum CBR variation, soil samples were made for triaxial tests. Three triaxial test specimens were made with different cell pressure variations of 0.5 kg/cm^2, 1.0 kg/cm^{2,} and 2.0 kg/cm^2 so that the Mohr-Coulomb collapse line could be made on the Mohr circle. For each condition, different values of cohesion and inner shear angle will be obtained according to the water content condition. From each condition, 3 Mohr circle graphs will be obtained. The inner shear angle together with the cohesion determines the soil due to the working stress in the form of soil lateral pressure. This value was obtained from measuring soil engineering properties in the form of a triaxial test with Unconsolidated-Undrained (UU) on each optimum variation of the FA, BA, and FABA mixture. The values of cohesion and friction angle in Mohr's circle 3 can be seen in

Table 8. Cohesion and Inner Shear Angle Values at Each Optimum Variation

No.	Stabilized Soil	Value	
		Cohesion (C)	**The angle of internal friction (φ)**
		kg/cm²	**⁰**
1	Soil + *Fly ash* 10 % incubation period 14 hari	0.031	33.3
2	Soil + *Bottom ash* 20 % incubation period 7 hari	0.935	25.9
3	Soil + (*Fly ash + Bottom) Ash* 20 % incubation period 14 hari	0.235	34.1

Source: Primary Data, 2023

When viewed from **Table 8**, the cohesion value of the stabilized soil has a range of values at 0.031 - 0.935 kg/cm². and the amount of inner shear angle ranges between 25.90^{0} and 34.10^{0} . According to (Braja, 1988) the value of the inner shear angle in the stabilized soil that the soil type is a clayey loam or dense sand.

CONCLUSION

1. From the comparison results the residual soil properties are included in the low plasticity sandy soil with a PI value of 14.45% < 17% and based on the JT-E2017 Freeway Technical Specifications the residual soil CBR value is less than 6%.
2. In terms of mechanical properties of residual soil after stabilization, the optimum mixture variation for each stabilization material can be obtained, namely fly ash 10% with a 14-day holding incubation period, Bottom ash 20% with a 7-days holding incubation period, and FABA 20% with a 14-days holding incubation period.
3. Alterations in the physical properties of the stabilized soil indicated notable changes, particularly in the values of water content (WC). At all stabilization ages, for 7 days the water content values with the addition of Fly ash 10% stabilizer and Bottom ash 20% tended to be the same but were different with the addition of stabilizer. FABA is 20% lower at 7 days of age and so on until 14 days of age. This is because the addition of the stabilizer Fly ash 10% and Bottom ash 20% fills the soil pores less than the addition of the stabilizer FABA 20%. The volume weight value increased with the addition of 20% FABA stabilizer, this value was greater than with the addition of 10% Fly ash and 20% Bottom ash stabilizers at the age of 0 – 7 days. The immersion time in the stabilization process causes the specific gravity (Gs) value to decrease and the number of pores to decrease as the immersion incubation period increases.
4. Changes in the mechanical properties of residual soil stabilized with Bottom ash content of 20% with an optimum holding incubation period of 7 days increase the CBR value of

2611.75% against the original soil CBR value. residual soil stabilized with FABA at 20% with an optimum holding incubation period of 14 days can provide an increase in CBR value of 3990. 61% to the original soil CBR value so it is found that the residual soil stabilized using Bottom ash at 20% with a CBR value = 9.49% qualifies as ordinary backfill soil for CBR> 6% and FABA at 20% with a CBR value = 14.32 qualifies as preferred backfill soil for CBR> 10%.

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