(e)ISSN 2656-8896 (p)ISSN 2656-890X
Journal of Infrastructure and Facility Asset Management – Vol. 6, Issue. 1, January 2024

Determination of Optimum Mixture Between FABA and Local Fill Soil for Road Embankment

Case study: Road Preservation of Sp. Kereng - Bereng Bengkel – Pilang – Pulang Pisau, Central Kalimantan

Raden Hisyam Syauqi Al Ghifari[1,a)], Noor Endah Mochtar[2,b)] & Soendiarto[3,c)]

[1)] *Magister Student, Civil Engineering Department, Sepuluh Nopember Institute of Technology, Surabaya,Indonesia*
[2)] *Civil Engineering Department, Sepuluh Nopember Institute of Technology, Surabaya, Indonesia*
[3)] *The National Road Implementation Agency for Central Kalimantan Region, Directorate General of Highways, Ministry of Public Work and Housing, Indonesia*

Correspondent : [a)]hisyam.syauqi@pu.go.id, [b)]noor_endah@ce.its.ac.id & [c)]soendiarto@pu.go.id

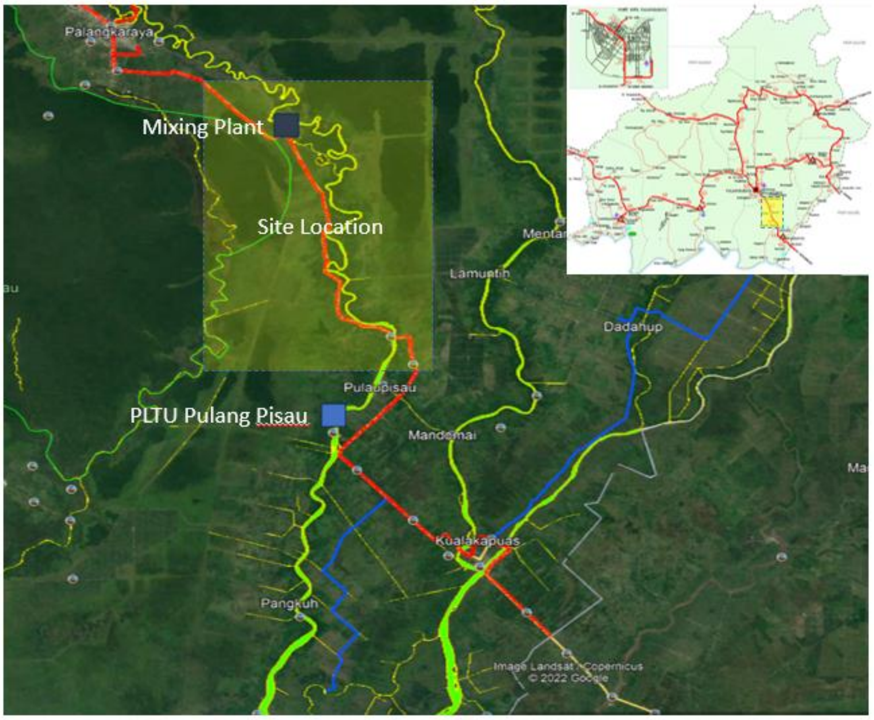
ABSTRACT

The road connecting Simpang Kereng, Bereng Bengkel, Pilang, and Pulang Pisau is part of the road network between two big cities in Kalimantan Island, Palangkaraya and Banjarmasin. These two big cities have a lot of activities that generate very high traffic volumes. Therefore, BPJN Central Kalimantan plans to make road improvements by widening the road. For this work, it needs a lot of good fill soil material that is very difficult to find in the nearest site; consequently, the cost of this project becomes very expensive. This condition can be done by mixing the local fill (good quality) soil with fly ash and bottom ash (FABA) as waste of Pulang Pisau Power Plant (PLTU PP). Because of that it needs to determine the optimum mixture between FABA and the local fill soil. The local soil, fly ash, and bottom ash can be classified as A-3 or SP, A-2-5 or SM, and A-3 or SP, respectively. Three different percentages of local soil, bottom ash, and fly ash mixtures were prepared (50:50:0), (40:40:20), and (30:30:40). They were tested to see which mixture that met the criteria for road embankments according to the General Specifications of Bina Marga Revision 2, 2018. The test results show that by mixing the local soil with FABA, the soaked CBR value decreases with the increase of FABA. The soaked CBR values of the local soil and the mixing materials, 50:50:0 (without fly ash), 40:40:20, and 30:30:40 are 17,78%, 17.22%, 15,87%, and 14.46%, respectively. It means that all the mixing materials meet the criteria for road embankment materials. Therefore, selection of the optimum mixing materials is based on the lowest unit price for material installed in the field, that is 30:30:40 mixture (30% local soil, 30% bottom ash, and 40% fly ash).

Keyword : bottom ash, fly ash, local fill soil, soil mixing.

INTRODUCTION

Roads are the lifelines of a country's economy. Infrastructure development is a crucial component of progress to accelerate and equalize economic growth, ultimately leading to the well-being of society. The availability of a road network in a region is a prerequisite for further development. According to Suprayitno and Soemitro (2018), Infrastructure asset management is the discipline, science, or program dedicated to overseeing and optimizing the management of infrastructure assets to ensure their sustainable, effective, and efficient functioning. Thus, a road should be constructed and managed using infrastructure asset management principles. The road network in Kalimantan Island is currently being built with a connectivity and travel time reduction approach, particularly for major cross-regional centers (Trans Kalimantan). The proper operation of infrastructure is one of the prerequisites that must be fulfilled for infrastructure to function effectively (Soemitro & Suprayitno, 2020). In Central Kalimantan Province, especially on the Simpang Kereng - Bereng Bengkel - Pilang - Pulang Pisau road, as shown in Figure 1.



(Source: The National Road Implementation Agency for Central Kalimantan Region, 2023)

Figure 1. Map of road reconstruction project location

Most of the road damage on that road section is not caused by the traffic passing over it, but mainly due to inadequate soil bearing capacity, as the road was originally built without soil improvement. When the road was constructed, it was required to comply with existing standards, but over time, the load of modern vehicles has exceeded the initial design. Due to the insufficient soil bearing capacity beneath the pavement layer, excessive deformation occurs in the pavement structure, leading to cracks that reflect from the subsoil to the road surface. As a result, maintaining infrastructure in optimal functional condition is crucial. This involves adherence to the fundamental principle of infrastructure asset management (Maulidha et al., 2022). To address this issue, the Ministry of Public Works and Housing through the National Road Implementation Agency for Central Kalimantan Region has been implementing a road preservation program annually. Road repair with preservation work, such as road widening, is conducted with a total handling length of 8.03 km with a width of 3 meters. Road widening on the Pilang – Pulang Pisau section at STA 0+000 – 1+000, STA 1+700 – 2+600, STA 10+800 – 14+500, and STA 34+100 – 34+200 with a total length of 5.7 km.

The road widening work will result in another issue, namely the availability of embankment material. The ongoing road construction emphasizes the importance of ensuring adequate material availability (Widayanti et al., 2019). Obtaining a large volume of embankment material in the area is challenging due to the relatively flat geographical conditions. However, if the excavation of embankment material is still conducted with sources from the surrounding work location (local material), it is suspected that the soil material will not meet the specified requirements due to the majority of Central Kalimantan being swampy and soft soil. Therefore, local soil needs to be optimized for use as road construction material that meets the specified requirements through soil mixing. Soil mixing using chemical methods can be applied to the study location because the fly ash bottom ash (FABA) waste produced by the Pulang Pisau

Power Plant (PLTU PP) is abundant. The use of a large amount of FABA will reduce the amount of bottom ash waste, which is expected to continue to increase significantly at the PLTU PP.

Therefore, using FABA as a soil mixing material for road embankments will reduce the accumulation of FABA waste. In contemporary times, incorporating waste materials into road infrastructure is deemed advantageous, both economically and environmentally sustainable. This aligns with Infrastructure Asset Management (IAM) Basic Principles, emphasizing the utilization of recycled materials in the planning and design of the road network. (Zhain, I. et al., 2022). Based on this explanation, there is a need for a study aiming to utilize FABA from the Pulang Pisau Power Plant as a stabilizing material for local soil in Central Kalimantan Province. The optimal mixing percentage between local soil material and FABA stabilizing material is crucial to determine.

LITERATURE REVIEW

Soil Material, Fly Ash, And Bottom Ash

The soil material used is in the form of local coarse-grained soil (sandy soil) utilized by the local service provider as the soil material for construction work in Central Kalimantan Province originating from the Karangan Subdistrict, Kutai Timur Regency, East Kalimantan Province. Fly ash is one type of artificial pozzolan (containing silica or aluminum silica) that does not have adhesive properties (self-cementing) but with its very fine particles, it can chemically react with lime and water to form adhesive materials (compounds with hydraulic properties) at normal temperatures. Coal bottom ash, a byproduct of the coal combustion process in power plants, consists of particles that are larger and heavier than fly ash. The characteristics of bottom ash exhibit considerable variation, influenced by factors such as the type of coal and the specific combustion system employed. Visual representations of the soil material, fly ash, and bottom ash are provided in Figure 2.

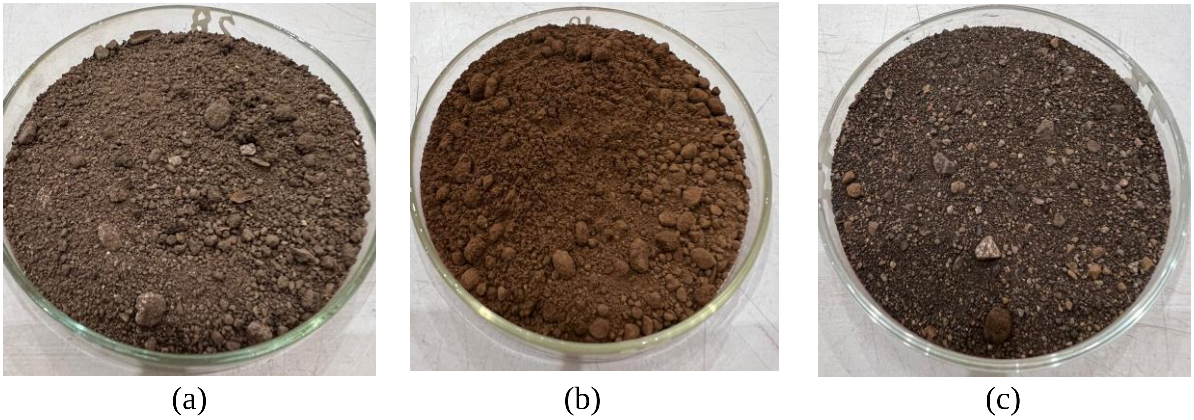

(a) (b) (c)

Figure 2. (a) Soil material, (b) fly ash, and (c) bottom ash.

Specifications For Selected Embankment Soil

The technical requirements for selected fill soil have been specified in Division 3 of the General Specification for Public Works 2018, 2nd Revision. Selected fill soil can be used as subgrade material, replacing ordinary fill soil, due to its higher bearing capacity. Based on these specifications, the requirements for selected fill soil include:

a. Exclusion of high plasticity soils (LL < 50) falling under class A-7-6 (clay) according to the SNI-03-6797-2002 classification system (AASHTO M145-91-2012) or class CH (high plasticity clay) according to the USCS classification system.
b. Absence of organic materials such as OL, OH, and Pt soil types in the USCS classification system, as well as soil containing leaves, grass, roots, and debris.

c. CBR (California Bearing Ratio) testing, conducted using the SNI 1744:2012 method, should yield a minimum CBR value of 10% after 4 days of soaking when compacted to 100% of the maximum dry density according to SNI 1742:2008.

Soil and FABA Mixture

Research has been conducted to investigate the impact of incorporating Fly Ash and Bottom Ash (FABA) as a stabilizing agent on California Bearing Ratio (CBR) values. by M. Khadafi Lembasy, Soewignjo A. N., and Ferry (2019). The testing was performed under six conditions: 28 days of curing tested directly, 28 days of curing and 4 days of soaking, 14 days of curing tested directly, 14 days of curing and 4 days of soaking, direct testing, and soaking. The highest CBR value was found in the composition of 60% clay soil + 15% bottom ash + 20% fly ash + 5% lime with a CBR value of 75.37% under the condition of 28 days of curing and 4 days of soaking.

In 2020, Lala Monang R. C. Z., Syawal S., and Soewignjo A. N. also conducted a study on the enhancement of unconfined compressive strength (UCS) in CH clay soil through the incorporation of fly ash, bottom ash, and cement. The study intentionally used CH or high plasticity clay soil, known to be problematic in construction projects. Testing was conducted on UCS at FABA mixture levels of 4%, 8%, 12%, and 16%, with no curing for original soil samples and curing for 0, 7, and 28 days for mixture samples. The research showed an increase in unconfined compressive strength from an initial 22.04 kPa to 94.79 kPa for the soil + 12% FABA + 5% cement mixture after 28 days of curing.

In 2021, Taufik H. conducted testing on the use of FABA as a soil stabilization material, indicating that the inclusion of both fly ash and bottom ash influences the physical and mechanical characteristics of the original soil. The ideal blend was achieved by incorporating 10% fly ash and 5% bottom ash.

In 2017, Khairul Umam, Soewignjo A. N., and Gunawan W. conducted research on the influence of sand gradation and clay content on the shear strength of soil. The study revealed that adding clay content to sand would increase the internal angle of soil shear and decrease cohesion values until the point where sand dominance still prevailed in the soil shear plane. Excessive clay content would shift dominance from sand to clay in the soil shear plane, reducing the internal angle of soil shear and increasing cohesion values.

Fly ash and bottom ash materials showcase varying physical and mechanical properties, contingent on the coal type, particle size, and the combustion process employed in power plants. Visual observations in the field suggest that bottom ash is sandy and non-cohesive, while fly ash is considered cohesive and clay-like. On the other hand, the local soil used is sandy and non-cohesive. In non-cohesive soil, water does not significantly affect soil behavior, but the dominant particle size distribution is crucial. Adding clay soil to sandy soil will make the soil gradation more diverse. Based on this, the research has determined that the percentage use of bottom ash is equal to the percentage use of soil (1:1 ratio). Meanwhile, fly ash in this study is used with a wider range, namely percentages of 0%, 20%, and 40% of the total mixture.

RESEARCH METHOD

In this study, testing was conducted on the combination of local soil with FABA mixture materials to determine the characteristics of the resulting stabilized soil mixtures. After determining the physical parameters of fly ash and bottom ash materials, a mixing process was conducted between these materials to be used as stabilizing agents, aiming to identify the physical properties of the mixtures and find the optimal composition. Based on the Special Specification (SKh) Bina Marga Number 1.5.15 regarding Embankment Foundation Layer Using Coal Ash/Fly Ash Bottom Ash (FABA), the determination of the mixture composition between fly ash and bottom ash was made for a minimum of three compositions. In this study, three variations of mixture ratios among these materials were tested, as shown in Table 1.

Table 1. Variations in Local Soil Content with FABA

No	Mixture Code	Local Soil Content	Bottom Ash Content	Ash Content
1	50500	50%	50%	0%
2	404020	40%	40%	20%
3	303040	30%	30%	40%

Analysis will be conducted on the results obtained from each testing phase. The initial phase involves identifying the optimal ratio between the indigenous soil and the combination of stabilizing agents, namely fly ash and bottom ash. Out of the three content variations formulated, a particular composition that demonstrates superior physical, mechanical properties, and cost is chosen. Subsequently, the blend of soil and FABA undergoes CBR testing to assess its CBR value in comparison to the original soil's CBR value before mixing. Further analysis is carried out to scrutinize alterations in the physical and mechanical properties of the soil pre- and post-mixing.

DATA COLLECTION

Physical property testing is conducted on soil material, as shown in Figure 1, which is used by the Road Construction Service Provider in the Sp. Kereng – Bereng Bengkel – Pilang – Pulang Pisau area originating from the Karangan Subdistrict, Kutai Timur Regency, East Kalimantan Province. The purpose of the physical property testing on soil is to determine its physical characteristics and soil classification. Physical property testing on the original soil includes several tests such as moisture content, bulk density, specific gravity, sieve analysis, and Atterberg limits, as follows. The results of the physical testing on the soil material can be seen in Table 2.

The testing of physical properties for fly ash and bottom ash materials is conducted to ascertain their physical characteristics and classification. This examination encompasses a range of parameters, including moisture content, bulk density, specific gravity, and sieve analysis, and Atterberg limits. The composition testing of fly ash and bottom ash is based on secondary data obtained from BPJN Central Kalimantan. The conducted tests include material composition of fly ash and bottom ash based on ASTM D 7348-21, loss of ignition based on ASTM D 3682-21, and the content of Sulfur Trioxide (SO_3) pollutants based on ASTM D 5016-16. The results of the composition testing for fly ash and bottom ash can be seen in Table 3. The overall summary of the physical property testing for fly ash and bottom ash materials is presented in Table 4.

From the composition testing results of fly ash and bottom ash materials, it is found that the sum of Silicon Dioxide (SiO_2), Aluminum Trioxide (Al_2O_3), and Iron (II) Oxide (Fe_2O_3) compounds is 69.32%. According to ASTM C-618 standards, fly ash is classified as Class C fly ash if it has ($SiO_2 + Al_2O_3 + Fe_2O_3$) content > 50%, Calcium Oxide (CaO) content > 10%, Sulfur Trioxide (SO_3) content < 5%, and Loss on Ignition (LOI) < 6%.

Table 2a. Summary of Physical Property Testing Results for Soil

No	Types of Testing	Testing Standard	Unit	Test Result
1	Moisture Content (w)	ASTM D-2216-71	%	4,995
2	Bulk Density (γt)	ASTM D-2937-71	gr/cc	1,370
3	Dry Density (γd)	ASTM D-2937-71	gr/cc	1,305
4	Specific Gravity (Gs)	ASTM D-854-58	-	2,646

Table 2b. Summary of Physical Property Testing Results for Soil

No	Types of Testing	Testing Standard	Unit	Test Result
5	Sieve Test	ASTM C103-46	-	Uniform Graded
6	Liquid Limit (LL)	ASTM D-423-66	%	NP
7	Plastic Limit (PL)	ASTM D-423-66	%	
8	Shringkage Limit (SL)	ASTM D-427-61	%	
9	Plasticity Index (IP)	ASTM D-423-66	%	
10	Soil Classification	ASTM D-422	-	SP
		AASHTO T88	-	A-3

Source: Test Result

Based on these criteria, The conclusion can be drawn that the fly ash material is categorized as Class C. Therefore, it is determined that any mixture using fly ash material does not require the addition of cementitious materials such as cement, as Class C fly ash has sufficient binding properties due to its high Calcium Oxide (CaO) content.

Table 3. Results of Composition Testing for Fly Ash and Bottom Ash Materials

No	Sample	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	Na_2O_3 (%)	K_2O (%)	SO_3 (%)	LOI (%)
1	Bottom Ash	60,78	5,96	14,45	9,25	6,65	0,66	0,48	0,35	2,24
2	Fly Ash	40,73	10,02	18,57	16,43	8,48	0,86	0,59	3,22	5,58

Source: The National Road Implementation Agency for Central Kalimantan Region, 2023

From the results of the physical property testing between soil, fly ash, and bottom ash materials, it is known that soil material (A-3/SP) and bottom ash (A-3/SM) can be categorized as non-cohesive soil, while fly ash (A-2-5/SM) is categorized as cohesive soil. In non-cohesive soil, water does not significantly affect the behavior of the soil, but the dominant particle size distribution is crucial. Based on this, it is determined that the percentage use of bottom ash can be maximized up to the same amount as the use of soil material (1:1 ratio). The sieve analysis results of the mixture between soil material and bottom ash can be seen in Figure 3.

Based on the AASHTO classification system, the mixture of soil and bottom ash falls into the category of fine sand A-3, and according to the Unified Soil Classification System (USCS), it is classified as SP (poorly graded sand). This classification indicates that the mixed material is non-cohesive. It suggests that when soil and bottom ash are mixed, there is no change in classification, whether using the AASHTO or USCS classification systems.

Table 4. Summary of Fly Ash and Bottom Ash Physical Property Testing Results

No	Types of Testing	Testing Standard	Unit	Test Result	
				Fly Ash	Bottom Ash
1	Moisture Content (w)	ASTM D-2216-71	%	48,465	6,374
2	Bulk Density (γt)	ASTM D-2937-71	gr/cc	0,953	1,537
3	Dry Density (γd)	ASTM D-2937-71	gr/cc	0,642	0,642
4	Specific Gravity (Gs)	ASTM D-854-58	-	2,680	2,727
5	Sieve Test	ASTM C103-46	-	Uniform Graded	Uniform Graded
6	Liquid Limit (LL)	ASTM D-423-66	%	50,000	NP
7	Plastic Limit (PL)	ASTM D-423-66	%	45,284	
8	Shringkage Limit (SL)	ASTM D-427-61	%	41,384	
9	Plasticity Index (IP)	ASTM D-423-66	%	4,716	
10	Soil Classification	ASTM D-422	-	SM	SP
		AASHTO T88	-	A-2-5	A-3

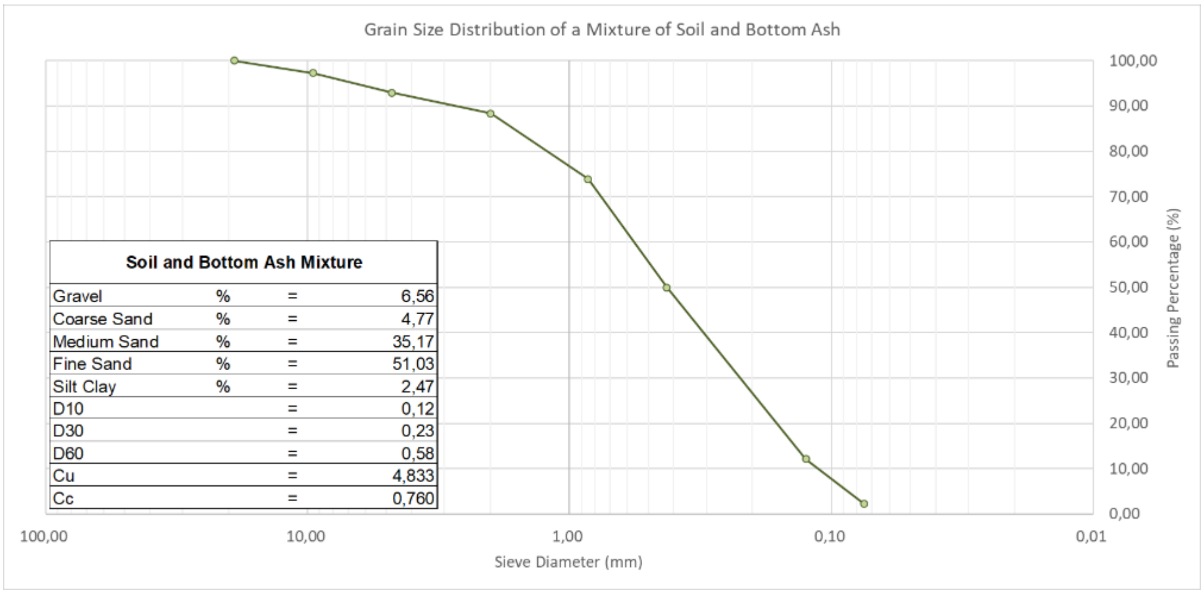
Source: Test Result

Non-cohesive soils, such as soil and bottom ash, lack attractive forces between particles, resulting in low cohesion values but significant shear strength. This contrasts with cohesive materials like fly ash, which has higher cohesion values but lower shear strength. The mechanical properties of the mixture of non-cohesive materials (soil and bottom ash) and cohesive material (fly ash) will be further investigated.

RESEARCH ANALYSIS

Physical Properties of Mixed Material

Physical property testing is conducted on the mixture of soil, fly ash, and bottom ash. There are three types of mixed materials that will undergo physical testing: a mixture of soil, bottom ash, and fly ash with a material combination of 50:50 (50% soil + 50% bottom ash), a material combination of 40:40:20 (40% soil + 40% bottom ash + 20% fly ash), and a material combination of 30:30:40 (30% soil + 30% bottom ash + 40% fly ash). The physical property testing of the mixed material aims to determine the physical characteristics and classification of each type of mixture. The examination of the physical properties of the blended material encompasses various tests, including specific gravity, sieve analysis, and Atterberg limits.



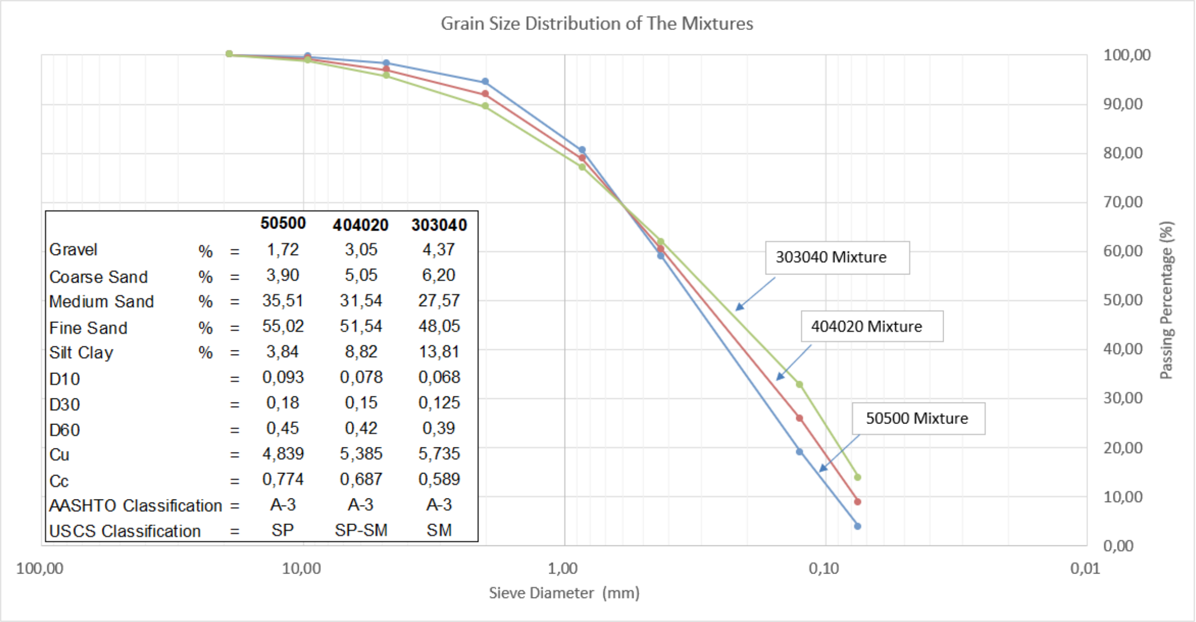
Soil and Bottom Ash Mixture			
Gravel	%	=	6,56
Coarse Sand	%	=	4,77
Medium Sand	%	=	35,17
Fine Sand	%	=	51,03
Silt Clay	%	=	2,47
D10		=	0,12
D30		=	0,23
D60		=	0,58
Cu		=	4,833
Cc		=	0,760

(Source: Test Result)

Figure 3. Results of particle size distribution testing for the mixture of soil and bottom ash material

The results of specific gravity (Gs) testing for each mixture type yielded average specific gravity values for the 50:50 mixture sample of 2.686, for the 40:40:20 mixture sample of 2.685, and for the 30:30:40 mixture sample of 2.684.

The results of the sieve analysis for the particle size distribution of the mixture are presented in a graph showing the relationship between the percentage of particles passing through the sieve and the sieve diameter, as seen in Figure 4. The classification of the mixture particles is as follows: gravel if retained on sieve no. 4, coarse sand if retained on sieve no. 10, medium sand if retained on sieves no. 20 and no. 40, fine sand if retained on sieves no. 100 and no. 200, and silt-clay if passing through sieve no. 200.



			50500	404020	303040
Gravel	%	=	1,72	3,05	4,37
Coarse Sand	%	=	3,90	5,05	6,20
Medium Sand	%	=	35,51	31,54	27,57
Fine Sand	%	=	55,02	51,54	48,05
Silt Clay	%	=	3,84	8,82	13,81
D10		=	0,093	0,078	0,068
D30		=	0,18	0,15	0,125
D60		=	0,45	0,42	0,39
Cu		=	4,839	5,385	5,735
Cc		=	0,774	0,687	0,589
AASHTO Classification		=	A-3	A-3	A-3
USCS Classification		=	SP	SP-SM	SM

(Source: Test Result)

Figure 4. Results of particle size distribution testing for all types of mixtures

The results of the particle size distribution testing for each mixture material show that the grain distribution is almost similar among the mixtures, as depicted in Figure 3. The escalating utilization of fly ash material correlates with an increase in the proportion of silt-clay particles. This shift leads to a modification in the classification of mixtures according to the USCS classification system. In the 50500 mixtures, it is categorized as poorly graded sand (SP). In the 404020 mixtures, the addition of 20% fly ash results in a classification of poorly graded sand with silt (SP-SM). Moreover, in the 303040 mixtures, the incorporation of fly ash up to 40% classifies it as silty sand (SM). Conversely, under the AASHTO classification system, all mixture types are designated as fine sand (A-3).

The results of the particle size distribution testing for the soil material indicate that the soil has a uniform graded particle size distribution dominated by sand particles with a small amount of silt-clay content from the fly ash and gravel materials. Calculations of the Coefficient of Uniformity (Cu) and Coefficient of Gradation (Cc) show that the particle size distribution of the soil in all types of mixtures has poor gradation ($Cu < 6$) with a poorly graded curve ($Cc < 1$). This aligns with the findings from the sieve analysis of the soil material, where the soil produces particles with poor gradation and a poorly graded curve.

Based on the consistency limit testing for each material, it is known that soil and bottom ash samples are of the sandy soil type (non-cohesive), while fly ash material is a sandy silt/clay material. The results of the consistency limit testing for each type of mixture (50500, 404020, and 303040) show that all three mixtures are still non-plastic. This is supported by the results of the particle size distribution testing for the mixture materials, which indicate that the 50500 sample is dominated by sand at 94.44%, the 404020 mixture is dominated by sand at 88.13%, and the 303040 mixture is dominated by sand at 81.82%. Therefore, the influence of water on sandy soil types (non-cohesive) is primarily determined by the particle size distribution of the material.

Analysis Of Soil and Mixture Density Test Results

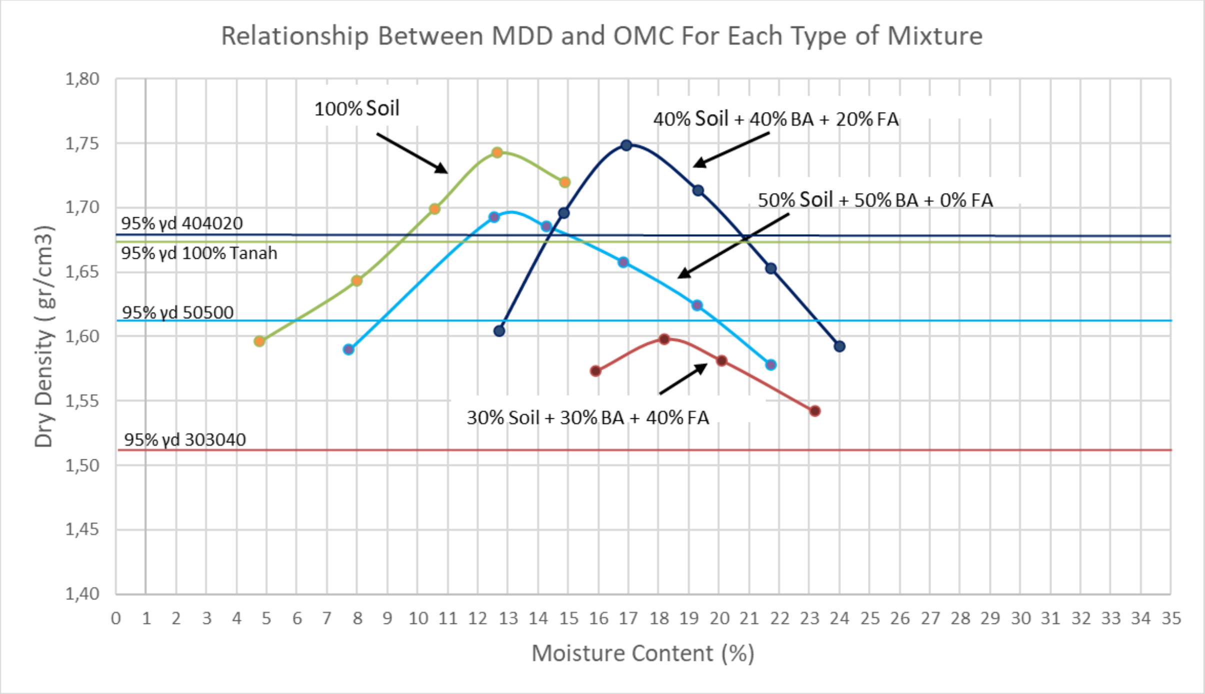
This test is performed to establish the correlation between the water content and the unit weight of the soil being analyzed, with the aim of establishing the optimum moisture content (OMC) and maximum dry density (MDD) of the tested soil sample. The laboratory testing process involves adding water to the native soil at various intervals to achieve the optimal moisture content and the highest dry volume. If the addition of water at a specific interval result in a decrease in the sample, it is because the previously solid-filled pore cavities are now being filled with water. The results of the wet soil volume weight calculations at each interval of water addition, according to the standard proctor. To establish the relationship between water content and volume weight, a graph is used to indicate the optimum moisture content (OMC) when the maximum dry weight (MDD) is reached, as explained by Proctor in 1933.

From the calculations of dry density (γd) and water content (w) for each test sample, the data is then plotted on a graph to identify the point of optimum moisture content (OMC) when the maximum dry density (MDD) is achieved. In the theory of compaction, each compaction graph will not exceed the graph of zero air voids (ZAV) and cannot be practically achieved, either in the laboratory or in the field. This is because there will always be air voids, no matter how much compaction effort is made. Therefore, the ZAV graph can be used as a compaction control. Based on the density testing of the soil material, the maximum dry density (MDD) obtained was 1.743 g/cm^3 with an optimum moisture content (OMC) of 12.64%. From the density testing of the mixture materials, the maximum dry density (MDD) was obtained as follows:

1. Mixture 50500: MDD of 1.697 g/cm^3 with an optimum moisture content (OMC) of 13.10%.
2. Mixture 404020: MDD of 1.750 g/cm^3 with an optimum moisture content (OMC) of 17.00%.
3. Mixture 303040: MDD of 1.598 g/cm^3 with an optimum moisture content (OMC) of

18.18%.

From the results of the density testing of the soil and mixture materials, the relationship between the maximum dry density (MDD) values at the optimum moisture content (OMC) can be compared as shown in Figure 5. From the figure, it can be observed that the 95% of the maximum dry density value for the mixture material 404020 mixture has a slightly higher moisture content compared to that of the original soil material. On the contrary, the types of mixtures 50500 and 303040 have 95% of the maximum dry density values significantly lower than the mixture 404020 and the soil material. Based solely on the density testing results, the mixture 404020 is considered the most optimum among the types of mixtures. However, additional mechanical testing is needed to assess the performance of these three types of mixtures and determine the most optimum mixture.



(Source: Test Result)

Figure 5. Graph of the relationship between MDD and OMC for each type of mixture

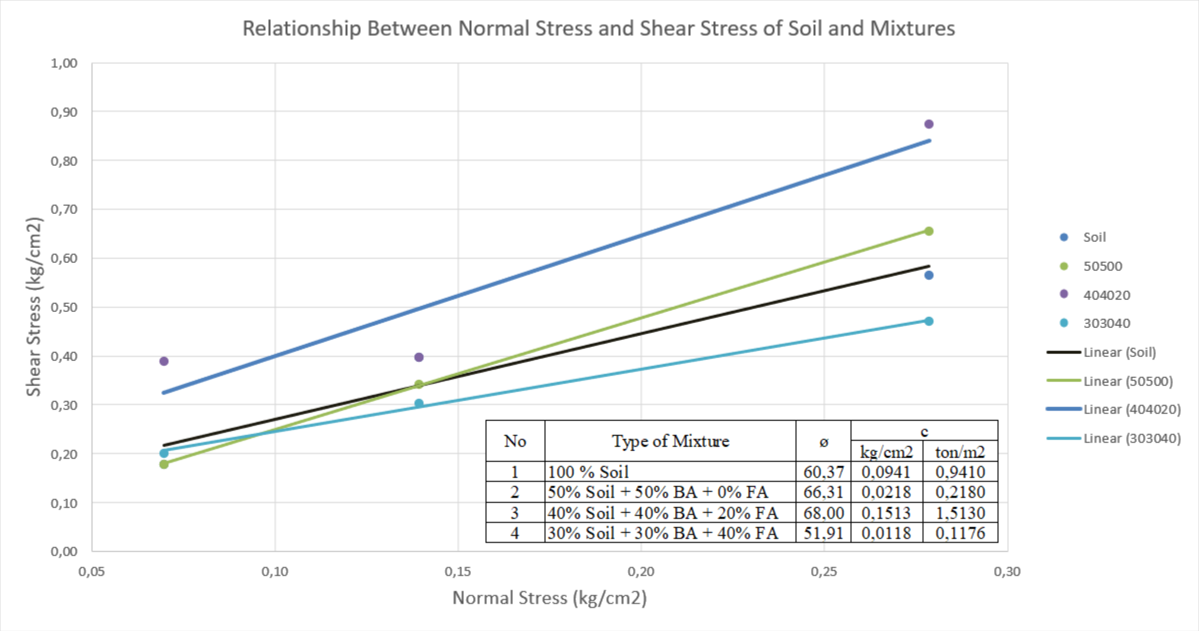
Analysis Of Direct Shear Test

Based on the outcomes of the direct shear testing on the soil material and the three types of soil mixtures with FABA, as shown in Figure 6, it is found that the highest shear angle (ø) and cohesion (C) values are obtained in the mixture 404020. The shear angle (ø) is 68.00 degrees, and the cohesion (C) is 0.1513 kg/cm^2. This can occur because the addition of fly ash, which is cohesive, up to 20% results in the filling of voids between soil and bottom ash particles. The filling of these voids produces a higher shear angle compared to the shear strength testing results of the soil material and the 50500 mixtures, which is dominated by sand particles.

The continued incorporation of fly ash, up to 40% as observed in the 303040 mixtures, results in a notable reduction in both cohesion and shear angle values. This decline could be ascribed to the hypothesis that adding fly ash in this study is akin to introducing silt-clay material. Shear strength tests on silt-clay typically yield a lower shear angle compared to the results from shear strength testing on sandy soil materials, such as soil and bottom ash. The cohesion value from direct shear tests shows that the mixture of the three types of materials is very small and can be considered zero.

Analysis Of CBR Test

From the test results, the CBR value for the first test of the soil material, as calculated previously, shows a CBR value of 14.59% at a 0.1-inch penetration and a CBR value of 18.09% at a 0.2-inch penetration. Thus, the CBR value for the first test is determined to be 18.09%. The calculation of the CBR value is repeated for all types of mixtures, and the average value is taken from the two samples for each type. The summary of the CBR test can be seen in Table 5.



No	Type of Mixture	ø	c	
			kg/cm2	ton/m2
1	100 % Soil	60,37	0,0941	0,9410
2	50% Soil + 50% BA + 0% FA	66,31	0,0218	0,2180
3	40% Soil + 40% BA + 20% FA	68,00	0,1513	1,5130
4	30% Soil + 30% BA + 40% FA	51,91	0,0118	0,1176

(Source: Test Result)

Figure 6. Relationship between shear stress and normal stress for all mixtures

Table 5. Summary of CBR Test Results

No	Type of Mixture	Sample	Moisture Content	Dry Density	CBR		CBR Average
					0,1'	0,2'	
			%	gr/cm3	%	%	%
1	100% Soil	1	13,36	1,70	14,59	18,09	17,78
		2	12,32	1,72	14,52	17,47	
2	50500	1	13,31	1,71	14,11	17,71	17,22
		2	13,51	1,70	13,27	16,74	
3	404020	1	17,11	1,75	13,63	15,67	15,87
		2	16,97	1,75	13,75	16,07	
4	303040	1	18,25	1,61	12,42	14,08	14,46
		2	17,88	1,58	12,79	14,83	

Source: Test Result

From the CBR test results on the three types of mixtures and soil material, It is evident that an increase in the percentage of fly ash in the mixture will decrease the CBR value. However, the mixture with a 0% fly ash content (50500) produces a CBR value that is nearly close to the CBR value of the soil material. This is because fly ash is classified as A-2-5/SM, which is a sandy silt material. It is known that silt materials will result in a lower CBR compared to coarse-grained materials such as sand.

Therefore, excessive utilization of fly ash in the mixture will lead to a further decline in the CBR value of the mixture. However, from the three types of mixtures, all mixtures can achieve

CBR values that meet the minimum CBR requirement for selected fill material according to the General Specification of Bina Marga Revision 2, 2018 (CBR > 10%).

Unit Price Analysis

From the results of the analysis of the unit price of work that has been calculated for each type of mixture, it can be seen that the more fly ash and bottom ash materials used, the more the price of work per cubic meter will be reduced. This is because in the analysis, the soil material used in the mixture is a material that must be purchased like materials in general, while the fly ash and bottom ash materials only require shipping transportation costs from PLTU Pulang Pisau to the quarry/construction material storage area that has been provided so that In terms of material prices alone, it can be cheaper. However, the equipment cost component is higher compared to using soil material because it requires longer working hours on heavy equipment to mix the material so that the material can be mixed evenly. The summary of the unit price can be seen in Table 6.

Table 6. Summary of Unit Price Calculations

No	Type of Mixture	Unit	Price	Gap
1	100% Soil	M^3	Rp347.000,00	-
2	50500	M^3	Rp303.300,00	12,59%
3	404020	M^3	Rp281.300,00	18,93%
4	303040	M^3	Rp259.256,96	25,29%

Source: Test Result

Determination Of Optimum Mixture Content

From a series of physical and mechanical tests on soil, fly ash, bottom ash, and their mixtures, the composition of fly ash and bottom ash (FABA) mixtures as a stabilizing material was determined. The recommended mixture for local soil is 303040, consisting of 30% soil, 30% bottom ash, and 40% fly ash. This mixture achieved a shear angle (ø) of 68.00° with a cohesion value of 1.513 tons/m². These results outperformed direct shear tests on other mixtures presented earlier. Furthermore, the CBR test yielded a CBR value of 14.46% for this mixture, meeting the criteria for road embankment materials according to the General Specification of Bina Marga Revision 2, 2018 (CBR > 10%). Although the 50500 dan 404020 mixtures had a higher CBR value at 17.78% and 17.22%, it had higher unit price value than the 303040 mixtures. Therefore, a mixture of 30:30:40 is the optimum mixture.

CONCLUSION

Based on the test result and analyses given above, it can be concluded as follows:

1. Fly ash taken from Pulang Pisau Power Plant (PLTU PP) can be classified as class C.
2. The local soil, fly ash, and bottom ash are classified as A-3 or SP, A-2-5 or SM, and A-3 or SP, respectively.
3. The soaked CBR value of local soil 17,78%; it decreases with the increase of FABA.
4. The mixing materials, 50:50:0 (without fly ash), 40:40:20, and 30:30:40, have soaked CBR value of 17.22%, 15,87%, and 14.46%, respectively.
5. All the mixing materials chosen met the criteria for road embankments according to the General Specifications of Bina Marga Revision 2, 2018 (CBR > 10%).
6. The optimum mixing materials based on the lowest unit price for material installed in the field is 30:30:40 mixture (30% soil, 30% bottom ash, and 40% fly ash).

PREFERENCE

[1] AASHTO. (2012). M145-91. *Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes*. AASHTO, Washington D. C.

[2] ASTM. (2014). C618-12a. *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*. ASTM International. Philadelphia.

[3] Badan Standarisasi Nasional. (2008). SNI 1744:2012. Cara Uji Kepadatan Ringan Untuk Tanah. BSN. Jakarta.

[3] Badan Standarisasi Nasional. (2012). SNI 1744:2012. Metode Uji CBR Laboratorium. BSN. Jakarta.

[4] Badan Standarisasi Nasional. (2022). SNI 9092:2022. Spesifikasi Timbunan Pilihan dan Lapis Fondasi Menggunakan Abu Batu Bara (Fly Ash dan Bottom Ash/ FABA). BSN. Jakarta.

[5] Direktorat Jenderal Bina Marga. (2020). *Spesifikasi Umum 2018 Untuk Pekerjaan Konstruksi Jalan dan Jembatan (Revisi 2)***.** Kementerian PUPR. Jakarta.

[6] Direktorat Jenderal Bina Marga. (2022). SKh-1.5.15. *Timbunan Pilihan dan Lapir Fondasi Menggunakan Abu Batu Bara/ Fly Ash dan Bottom Ash (FABA).* Kementerian PUPR. Jakarta.

[7] Maulidha Z.W, et al. (2022). “Geotechnical Mapping for Soil Physical and Mechanical Parameters and Hard Soil Depth in Badung Regency”. *Journal of Infrastructure and Facility Asset Management – JIFAM 4(2) August 2022.*

[8] Lembasy, M. Khadafi, Soewignjo A. N., dan Ferry. (2019). *Studi Penambahan Fly Ash dan Bottom Ash Terhadap Nilai CBR Dan Swelling Potential Pada Tanah Lempung.* ACE Conference: Universitas Riau. Pekanbaru.

[9] Soemitro, R.A.A. & Suprayitno, H. (2020). “Preliminary Reflection on Basic Principle of Operation Management for Public Work Infrastructure Asset Management”. *Journal of Infrastructure and Facility Asset Management - JIFAM 2(Sup1) December 2020.*

[10] Suprayitno, H. & Soemitro, R.A.A (2018). “Preliminary Reflexion on Basic Principle Infrastructure Asset Management*”. Jurnal Manajemen Aset Infrastructur & Facility – JMAIF 2(1) March 2018.*

[11] Umam, Khairul, Soewignjo A. N., dan Gunawan W. (2017). Pengaruh Gradasi Pasir Dan Kadar Lempung Terhadap Kuat Geser Tanah. FTEKNIK Volume 4 No.1. Universitas Riau. Pekanbaru.

[12] Widayanti, Ari, et al. (2019). “Gradation Analysis of Reclaimed Asphalt Pavement from National Road as Asphalt Concrete Layer”. *Journal of Infrastructure and Facility Asset Management – JIFAM 1(1) March 2019.*

[13] Zhain I., et al. (2022). “The Effect of Addition RAP as Quality Improved for Hot Paved Mixtures”. *Journal of Infrastructure and Facility Asset Management – JIFAM 4(1) April 2022.*