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Utilization of Spent Bleaching Earth Waste on Lime-Soil Stabilization for Road Body Foundation Layer Based on Soil Mechanical

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Abstract

Soil stabilization is mixing soil with specific materials to improve the soil's technical attributes to meet specific technical requirements, such as increasing its stability. One stabilization method is chemical stabilization, which utilizes mixing heaped soil using lime and Spent Bleaching Earth (SBE). This research is focused on the effect of mixing lime with SBE for soil stabilization with maintenance time between 0, 7, and 14 days. The amount of lime used in the research is 4% from the soil dry weight with variations of the SBE mixture of 5%, 10%, 15%, and 20%. The conclusion obtained in this study was that adding SBE could increase the maximum dry density up to a percentage of 10%. Using SBE of more than 10% reduces the maximum dry density value but increases the optimum moisture content. From the mechanical attributes testing carried out, it can be seen that a percentage of 10% can increase the results of mechanical testing, while an increment above 10% will reduce the mechanical results. Based on the CBR and UCS test results, we found that lime and SBE mixture can pass the attributes limit for a grade S aggregate foundation layer and full-fill the requirement as a road body foundation layer. So, it can be concluded that lime and SBE mixture can be used as a road body foundation layer but has not reached the target for road foundation layers and requires maintenance for some time.

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1. Introduction

Every civil engineering structure is to be found on the soil (Babu & Poulose, 2018). In planning the construction of a road, it is necessary to observe the subgrade condition of the road's structure pavement, which is essential in road construction because road pavement performance mainly depends upon the properties of subgrade soil (Dhatrak & Kolhe,2022). The layer itself needs to be planned in accordance with the existing rules to fulfill the required mechanical attributes such as carrying capacity and to support in safe conditions the loads applied by several works (Tinoco et al, 2021).

The subgrade must have an excellent quality to support a good road body foundation layer. A bad subgrade could cause a lousy soil carrying capacity where sometimes it will need a soil adjustment to fix the soil characteristics and carrying capacity so it could be used as a subgrade for the road body foundation layer.

Soil is a mixture of minerals, organic matter, gases, liquids, and countless organisms supporting life on Earth. The soil does not always meet the desired features. For this reason, it is necessary to intervene in the soil to gain needed properties (Afrin,2017). If the strength of the soil is poor, soil stabilization is generally required to enhance the mechanical properties of the soil (Andavan & Kumar, 2020). Soil stabilization is mixing soil with a particular soil or cementing material to improve the soil's mechanical attributes to fulfill some specific properties (Calik & Sadoglu,2013). Soil stabilization is a vital work package in road construction (Tan et al,2020). Soil adjustment can be accomplished by different methods, for example, compaction, soil substitution, and so on (B.A. Mir, 2015). There are two stabilization methods, which are mechanic stabilization and chemical stabilization. Chemical stabilization stabilizes the soil by adding a chemical component with specific characteristics to help fix the soil attributes and its carrying capacity. Soil stabilizers are generally categorized as traditional and non-traditional stabilizers; traditional ones include lime, and non-traditional ones such as asphalt (Manzoor & Yousuf, 2020). Lime is one of the materials that is effective for soil stabilization because lime is used as an excellent soil stabilizing material for highly active soils that undergo frequent expansion and shrinkage (Sabzi, 2018). Lime is the next most used calcium-based soil stabilizer.

Many industrial wastes like fly ash have been used in soil stabilization (James & Pandian,2015). This research conducted a chemical stabilization experiment using a heap land mixture and lime and Spent Bleaching Earth (SBE). SBE is a type of solid waste in palm oil refining (Ashari & Darmawan, 2018). SBE is commonly dumped in landfills, and due to the high cost of this dumping, it is necessary to use that wasted material for other applications in the industry (Loh et al.,2013). The use of SBE in civil engineering can be found in SBE with 50% composition mixed as a material for making light brick that has fulfilled the requirement for SNI 03-6861-2002 about a general requirement for construction bricks (Raksi et al, 2009). So, it can be concluded that SBE can be used for experimentation to fix the subgrade for heap soil.

By considering the past research, the purpose of this research is to show how the use of SBE can reduce the usage of lime as the stabilization component, effectively increase soil stability, and find out the different composition and curing times for each component of soil mechanical attributes.

2. Materials and Methods

2.1 Theoretical Framework

One of the efforts to improve soil characteristics is soil stabilization. Using lime and SBE as soil stabilization materials to study the heap soil mechanical improvement rate before and after stabilization.

The testing of soil mechanical attributes consists of *Compaction Test* (ASTM D 698-12), *California Bearing Ratio* (CBR) (ASTM D 1882-21), *Unconfined Compressive Strength* (UCS) (ASTM D 2166), *Direct Shear Test* (ASTM D 3080-11) , *Consolidation* (ASTM D 4186). The results from mechanical attributes can be obtained after the experiment. Every result obtained will be adapted to the road body foundation layer based on the specification on the 2018 General Specification for Road and Bridge Construction Works (2nd Revision).

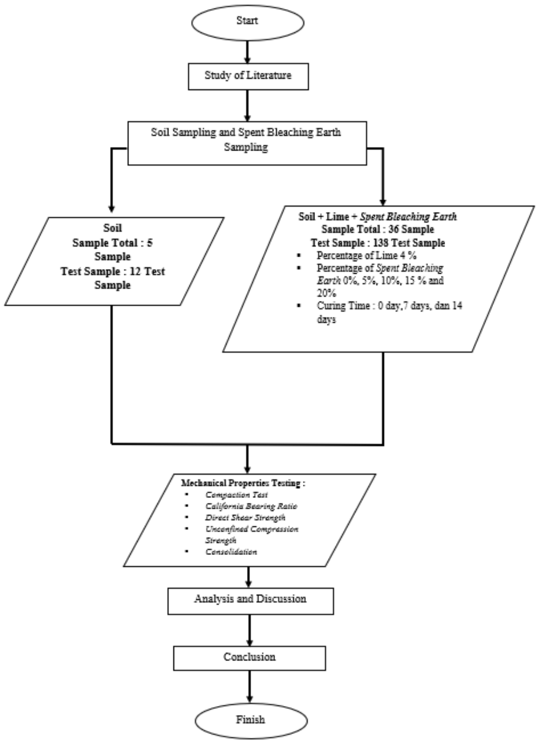

Fig 1. Research Flowchart

2.2 Research Location

The object of research that will be used are heap soils from Peniraman Jalan Raya Nusapati Sungai Pinyuh, Mempawah Regency, and the Spent Bleaching Earth are sourced from PT. Energi Unggul Persada company's vegetable oil processing industry, Sungai Limau Village, Mempawah Regency, and the research location is in the Soil Mechanics Laboratory at Universitas Tanjungpura, Pontianak.

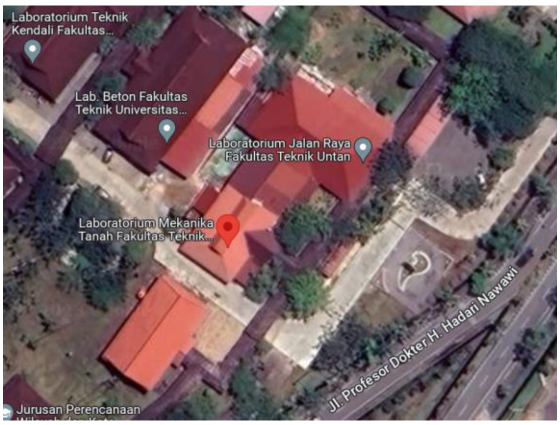

Fig 2. Research Location on Soil Mechanics Laboratory, Tanjungpura University, Pontianak

Fig 3. Quarry Location at Peniraman Jalan Raya Nusapati Sungai Pinyuh, Mempawah Regency

Fig 4. SBE Location at PT.Energi Unggul Persada, Mempawah Regency

2.3 Data Collection Methods

The data collection methods used in this study are:

1. Literature Study

This investigation leads to the development of preliminary hypotheses, which serve as provisional responses to the current research questions. Additionally, this literature review yields secondary data derived from prior research findings, which can be employed as supplementary data for analysis.

2. Experimental Study

An experiment is carried out within a laboratory setting involving the creation of multiple test samples and conducting tests to gather the necessary data. This data is subsequently analyzed and employed to test hypotheses derived from theoretical insights gleaned through a review of existing literature. In this experimental investigation, primary data is acquired directly from original soil tests conducted for soil stabilization testing.

This research uses primary and secondary data. Fieldwork (soil sampling) and laboratory work (sample testing) exist.

Soil sampling in this research consists of hampered soil and non-hampered soil. This research conducts soil mechanical attributes testing with lime compound and SBE variations, consisting of soil compound mixed with 4% lime combined with SBE variations of 5%, 10%, 15%, and 20% with an aging time of 0, 7, and 14 days.

Table 1. Test Mixture Variations Code

No	Mixture Variations	Variations Code
1	S	S
2	S + Lime 4%	SL
3	S + Lime 4% + SBE 5%	SLS 05
4	S + Lime 4% + SBE 10%	SLS 10
5	S + Lime 4% + SBE 15%	SLS 15
6	S + Lime 4% + SBE 20%	SLS 20

Table 2. Number of Test Samples

No	Mixture Variations	Compaction	CBR	UCS	Direct Shear	Consolidation
1	S	1	2	1	1	1
2	S + Lime 4%	1	2	1	1	1
3	S + Lime 4% + SBE 5%	1	2	1	1	1
4	S + Lime 4% + SBE 10%	1	2	1	1	1
5	S + Lime 4% + SBE 15%	1	2	1	1	1
6	S + Lime 4% + SBE 20%	1	2	1	1	1
Smple Total		**6**	**12**	**6**	**6**	**6**
				36		

Table 3. Number of Test Objects

No	Mixture Variations	Compaction	CBR	UCS	Direct Shear	Consolidation
1	S	5	2	1	3	2
2	S + Lime 4%	5	4	6	9	1
3	S + Lime 4% + SBE 5%	5	4	6	9	1
4	S + Lime 4% + SBE 10%	5	4	6	9	1
5	S + Lime 4% + SBE 15%	5	4	6	9	1
6	S + Lime 4% + SBE 20%	5	4	6	9	1
Smple Total		**30**	**22**	**31**	**48**	**7**
				138		

2.3.1 Preparation of Test Objects

Prior to commencing the research, the necessary testing apparatus was prepared. This equipment includes devices for soil drying and crushing, a sieve for filtering the crushed soil to undergo sieve testing, and Spent Bleaching Earth and lime in proportions as prescribed for the mixture.

2.3.2 Material Mixing

The blending of lime and soil components is accomplished through manual stirring. Mix the combination using a small shovel on a clean metal tray or metal table following these steps:

1. Thoroughly mix the lime with the soil that has been sifted according to the required test specifications.
2. Introduce water by the optimal moisture content determined through density testing and blend until a uniform mixture is achieved.
3. Store the material in a plastic bag for approximately 5 hours, after which the test specimens can be prepared.

2.3.3 Curing Time

The curing duration discussed in this study involves carefully preserving test specimens to prevent water loss. It also entails maintaining a humid environment for specified intervals, namely 0 days, seven days, and 14 days. The specimens were cured inside a desiccator for direct shear and consolidation tests. Plastic bags encase the specimens intended for free compressive strength testing. Gunny sacks were employed to house the samples designated for the California Bearing Ratio tests in a moist environment. The methodology for conducting this curing period follows the guidelines outlined in SNI 03-6798-2002, which outlines the procedures for creating and treating cement soil specimens for compressive and flexural strength testing in a laboratory setting.

2.4 Analysis Method

After the necessary data is collected from the mechanical attributes test in the laboratory, there is a manual analysis of *Compaction Test*, *California Bearing Ratio* (CBR), *Unconfined Compressive Strength* (UCS), *Direct Shear Test*, dan *C Compaction Test (ASTM D 698-12), California Bearing Ratio (CBR) (ASTM D 1882-21), Unconfined Compressive Strength (UCS) (ASTM D 2166), Direct Shear Test (ASTM D 3080-11), Consolidation (ASTM D 4186).* After that, the results will be examined based on the requirements and criteria for road body layer foundation for the 2018 General Specification for Road and Bridge Construction Works (2nd Revision).

3. Result and Discussion

Below are the calculation results after mechanical attributes tests in the laboratory.

3.1 Original Soil Test

Table 4. Original Soil Test Result

No	Test Type	Test Result
1	Moisture Content (Undisturbed Soil) (w = %)	41,017
2	Moisture Content (Undisturbed Soil) (γ_w = gr/cm^3)	1,272
3	Moisture Content (Compacted Soil) (W_{opt} = %)	24,155
4	Unit weight (γ_w = gr/cm^3)	1,143
5	Specific grafity (Gs)	2,611
6	Liquid limit (LL = %)	43,290
7	Plastic limit (PL = %)	29,038
8	Plasticity Index (IP = %)	14,252
9	Shrinkage limit (SL = %)	41,615
	Particle size distribution analysis (%)	
10	Sand	20,000
	Silt	62,000
	Clay	18,000

Table 5. Original Soil Gradation Test Results

Sieve Size		Retained Weight	Total		
			Retained Weight	% Retained	% Passing
Inch	mm	gr	gr	%	%
2"	50,000	0,00	0,00	0,00	100,00
1½"	37,500	0,00	0,00	0,00	100,00
1"	25,000	0,00	0,00	0,00	100,00
3/8	9,500	70,00	70,00	3,50	96,50
#4	4,750	145,00	215,00	10,75	89,25
#10	2,000	140,00	355,00	17,75	82,25
#40	0,425	85,00	440,00	22,00	78,00
#200	0,075	445,00	885,00	44,25	55,75

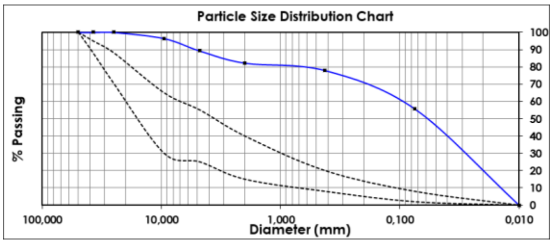

Fig 7. Gradation Soil Results

From the original soil gradation test result, it can be concluded that the original soil used did not fulfill the requirement as a grade B aggregate foundation layer.

3.2 Compaction Test

Table 6. Original Soil *Compaction Test* Result

No	Mixture Variations	Result
1	Optimum Moisture Content (wOpt), %	24,090
2	Maximum Dry Density (γ_{dmax}), gr/cm^3	1,463

Table 7. Original Soil Compaction Test Result Mixed with Spent Bleaching Earth and Lime Compound

Mixture Variations	W_{opt} (%)	γ_{dmax} (gr/cm^3)
SL	22,22	1,474
SLS 05	21,56	1,488
SLS 10	21,91	1,494
SLS 15	22,29	1,485
SLS 20	23,28	1,460

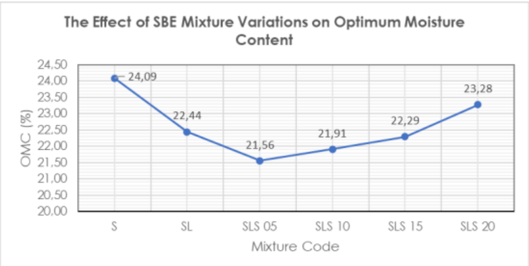

Fig 8. Graph of the Effect of SBE Mixture Variations on Optimum Moisture Content

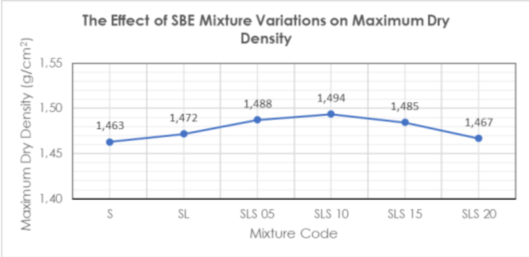

Fig 9. Graph of the Effect of SBE Mixture Variations on Maximum Dry Density

From Fig 8 and Fig 9, it can be concluded that the addition of lime to the original soil can increase the maximum dry density and reduce optimum moisture content, and the addition of SBE material can also increase the maximum dry density better compared to the original soil that is mixed with lime. The most optimum SBE addition percentage is 10% because it gave the highest maximum dry density.

3.2 *California Bearing Ratio* (CBR) Test

Table 8. Soil Mixed with Lime and SBE CBR Result

Mixture Variations	CBR Results (%)			
	Unsoaked			Soaked
	0	7	14	
S	24,675	25,797	26,171	5,421
SL	48,977	70,101	81,317	50,099
SLS 05	51,220	75,896	84,308	54,211
SLS 10	57,389	84,495	90,290	61,876
SLS 15	49,351	72,531	82,630	52,342
SLS 20	42,995	61,876	72,530	43,369

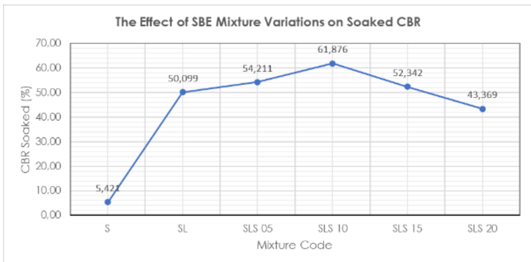

Fig 10. Graph of the Effect of Mixing SBE Variations + Lime on Soaked CBR

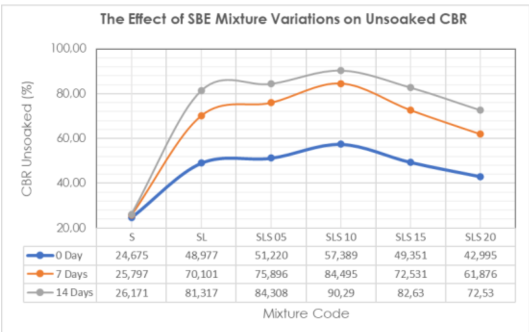

Fig 11. Graph of the Effect of Mixing SBE Variations + Lime on Unsoaked CBR

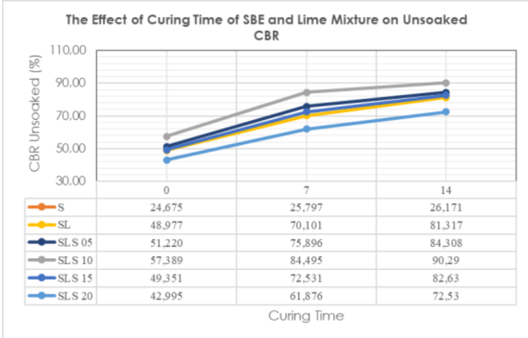

Fig 12. Graph of the Effect of the Mixture's Aging Time on Unsoaked CBR with SBE and Lime

Figs 10 and 11 above show that adding the SBE compound will increase the soaked CBR and unsoaked CBR score on the original soil. The highest score on the experiment is obtained with the 10% SBE variation with 14 days of aging time. This is because in the compound variation occurs an optimum cementation process that resulted in the highest score compared to other variations.

From Fig 12, it can also be concluded that the effect of mixing soil, lime, and SBE on aging time is that the longer aging time will result in a higher CBR score, with the highest score with the 10% SBE variation with 14 days of aging time.

3.3 *Unconfined Compressive Strength* (UCS) Test

Table 12. Soil UCS Result with SBE and Lime Mixture

Mixture Variations	UCS (kg/cm^2)		
	0	7	14
S	4,467	4,888	4,971
SL	6,133	13,700	15,113
SLS 05	6,461	13,820	15,374
SLS 10	7,268	14,700	17,224
SLS 15	6,078	12,100	14,046
SLS 20	5,533	8,493	12,331

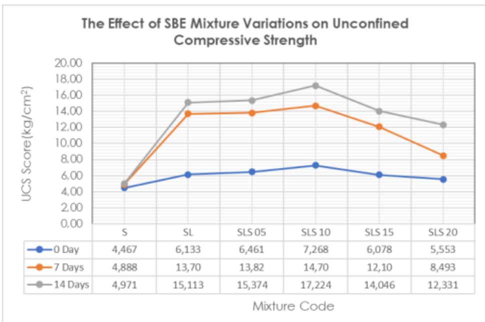

Fig 13. Graph of the Effect of SBE Variations Mixture on UCS Score

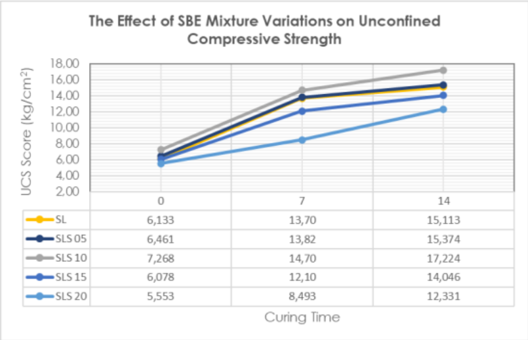

Fig 14. Graph of the Effect of Aging Time on UCS Score

From Figs. 13 and 14, it can be concluded that adding an SBE mixture can increase the free compressive strength score of the original soil's free compressive strength, even though the improvement on each mixture variation is different. We can also observe that the effect of aging time on the score is that the longer aging time will result in a higher score, where the highest score is obtained after 14 days of aging time with 10% SBE mixture variation.

3.3 *Direct Shear Test*

Table 13. Soil's *Direct Shear Test* Result with SBE and Lime Mixture

Mixture Variations	Direct Shear Test					
	0		7		14	
	c	ϕ	c	ϕ	c	ϕ
S	0,130	37,603	0,148	38,291	0,157	38,883
SL	0,483	38,544	0,595	41,851	0,601	42,158
SLS 05	0,532	39,833	0,610	43,128	0,695	44,000
SLS 10	0,622	42,079	0,652	44,917	0,725	46,468
SLS 15	0,523	38,799	0,604	42,690	0,683	43,714
SLS 20	0,510	38,628	0,601	42,310	0,637	42,907

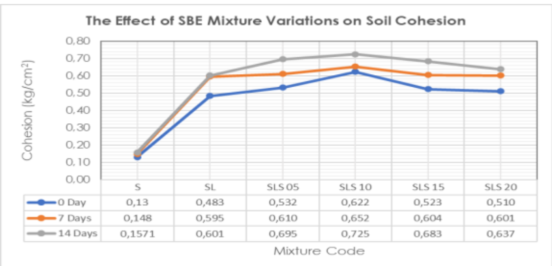

Fig 15. Graph of the Effect of the Mixture Variation on Soil Cohesion Value

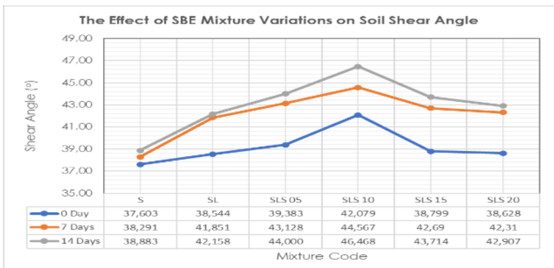

Fig 16. Graph of the Effect of the Mixture Variation on Soil Shear Angle Value

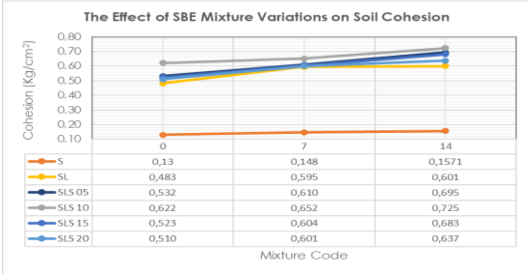

Fig 17. Graph of the Effect of Aging Time on Soil Cohesion Value

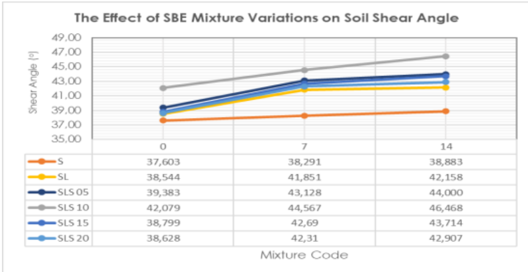

Fig 18. Graph of the Effect of Aging Time on Land Shear Angle Value

Pictures 15, 16, 17, and 18 show that an increase in the SBE mixture will also increase the cohesion and the land shear angle value from the original soil value. From the aging time effect, we can also observe that a longer aging time will result in a higher cohesion and shear angle value.

An increase in cohesion and shear angle value based on an addition to the SBE mixture is caused by cementation procured on the combination of soil, lime, and SBE.

3.4 *Consolidation* Test

Table 14. Original Soil *Consolidation* Test Result

No	Testing	Result
1	C_c	0,26575
2	C_v	0,01330

Table 15. Soil *Consolidation* Test with SBE and Lime Mixture Result

Mixture Variations	C_c	C_v
SL	0,111	0,0185
SLS 05	0,100	0,0196
SLS 10	0,086	0,0284
SLS 15	0,106	0,0179
SLS 20	0,113	0,0163

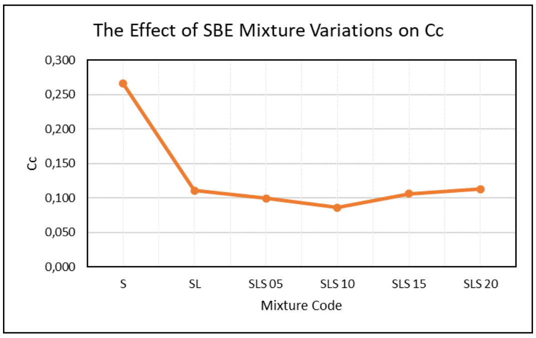

Fig 19. Graph of the Effect of Mixture Variations on Cc

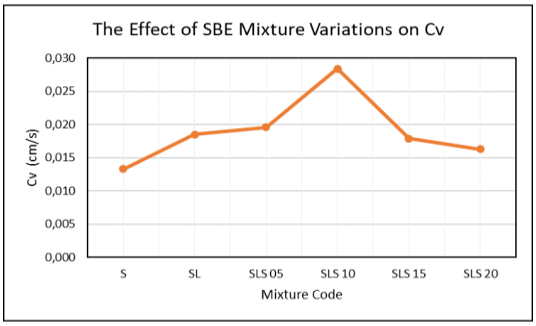

Fig 20. Graph of the Effect of Mixture Variations on Cv

From Figs. 19 and 20 above, we can observe that adding to the SBE mixture can decrease the Cc score with the lowest value on the 10% SBE mixture variation and increase the Cv score with the highest value on the 10% SBE mixture variation.

3.5 Test Analysis

The test results show a stable and optimum value by adding 10% SBE and 4% lime mixture. Our data shows that compaction with maximum dry density is 1,494 gr/cm3. Therefore, the conclusion is that because the maximum dry density is obtained with the 10% mixture variation, other tests produce the highest results because that variation had the highest dry maximum density, which affects other test results and causes them to produce the highest result compared to other variations. However, the test's final results still did not fulfill the standard score to be used as a layer foundation. Therefore, a mix design is needed to determine whether a lime with an SBE mixture can achieve the desired target score.

Based on 2018 Bina Marga Specification for Roads and Bridges the test results from the variation with 10% SBE and lime mixture can be used as a B class aggregate foundation layer with a minimum CBR value of 60%, while the test result was 61,87% meanwhile the variation with 4% lime mixture and the mixture with 4% lime and 5% SBE, 15% SBE already full-fillled the requirement as a S class aggregate foundation layer that has the minimum CBR value of 50% while the test results sequentially were 50,099%, 54,211%, and 52,342% while the variation with 20% SBE and 4% lime mixture only full-fill the soil stabilization score with the CBR target of 15% while the variation's test result is 43,369% whereas for the free compression strength test based on the Bina Marga Specification for the Roads and Bridges none of the test results full-fillled the requirement to become a foundation layer base soil with the minimum requirement value of 20 kg/cm^2 whereas to full-fill the UCS requirement for the road shoulder foundation with a minimum value of 14 kg/cm^2 and a target value of 18 kg/cm^2 the variation which full-fills the requirement were the one with 7 days of aging time with a mixture of 4% lime and 10% SBE with the test result of 14,70 kg/cm^2.

3.6 Mix Design Based on UCS Result for Road Body Foundation Layer

As for the results of the mechanical attributes, the optimal amount is obtained with the combination of lime and SBE on lime soil stabilization with the 10% mixture variation; then, a mixed six design was made for the result of the UCS test.

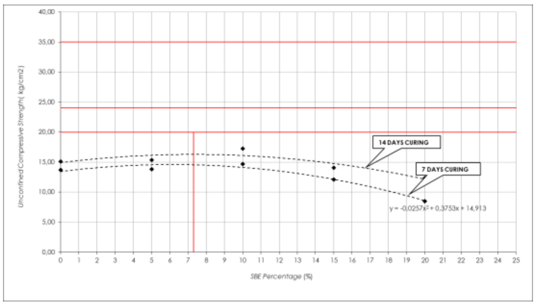

Fig 21. Mix Design Based on UCS Value

From Fig 21 above, it was shown that the optimal SBE value as a mixture for the soil foundation layer is 7.30% with 14 days of aging time. Therefore, using SBE with optimal value can be used as an addition for lime soil stabilization for the road body foundation layer with 14 days of aging time.

4. Conclusion

Based on the research that has been conducted in the laboratory and the results of the analysis of soil mixed with a mixture of lime and SBE and combined with curing time, it can be seen that the higher the percentage of SBE to the total weight of the soil, the optimum water content will increase and on the contrary the maximum dry density tends to decrease, this is because the presence of SBE changes the composition of fine-grained particles proportionally, where the more SBE added will cause more fine-grained particles in the soil. More fine-grained particles will cause the specific surface to become more prominent, increasing the water absorption capacity and thus increasing the bearing capacity of the field.

Based on the 2018 Bina Marga General Specification, the soil's CBR (California Bearing Ratio) and UCS (Unconfined et al.) tests indicate that a soil mixture containing 4% lime + 10% SBE (Stone Base Equivalent al.cessary criteria for a B class aggregate foundation layer, this is evidenced by a soaked CBR value of 61.88%. Additionally, a variation of 4% lime + 5% SBE fulfills the requirements for a S class aggregate foundation layer, while a mixture of 4% lime + 20% SBE satisfies the criteria for base soil stabilization. Furthermore, the UCS value of 14.70 kg/cm2 meets the specifications for a road shoulder foundation layer after an aging time of 7 days.

The direct shear test yielded a land shear angle value of 37,603o and a cohesion value of 0.13 kg/cm2 with no aging time, 38,291o and 0.148 kg/cm2 with two days of age time, and 38,883o and 0.157 kg/cm2 with 14 days of aging time.

In the consolidation test, the lowest Cc value was obtained when the SBE was varied by 10%, yielding a value of 0.086. Conversely, the highest Cy value recorded was 0.0284 cm/s. Based on the results of multiple tests conducted, it can be inferred that incorporating Spent Bleaching Earth waste as a constituent for soil stabilization can potentially enhance the load-bearing capacity of the soil heaps observed in Peniraman village. This conclusion is drawn from analyzing the mechanical properties derived from the tests above.

5. Acknowledgment

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6. Author's Note

Everything in this article is authentic because it summarizes my research with Mr. Dr. Ing. Ir. Eka Priadi, M.T., and Mrs. Vivi Bachtiar S.T., M.T., IPM. I, as the author, claim that there was no conflict during this journal publication, and there were no other parties that published this journal, this journal is free from any plagiarism.

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