JSE Journal of Science and Engineering, Vol. 4, No.1 (page: 48-57)
e-ISSN: 2723-3944 July 2025
DOI: https://doi.org/10.30650/jse.v4i1.4945

Innovation in Road Construction Materials: A Study on the Combination of Biochar and Cement in Improving Subgrade Bearing Capacity

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Abstract – Road infrastructure development often faces significant challenges due to low bearing capacity of the subgrade, especially when dealing with peat soil. This condition can lead to excessive settlement, deformation, and premature damage to the road pavement, resulting in high maintenance costs. Peat soil is inherently poor in quality, making it uneconomical to use as a subgrade for road pavements. The condition of peat soil significantly impacts road construction in Central Kalimantan Province. Therefore, one effective way to address this issue is through soil stabilization. This research aims to explore the potential of biochar and cement as stabilizing agents to improve the bearing capacity of peat soil. The study involves a series of laboratory tests, including initial physical property tests of the original peat soil, as well as index and mechanical strength tests after the addition of a combination of biochar and cement. The biochar used in this research is derived from coconut shells.The conducted tests include compaction tests to determine the maximum dry density and optimum moisture content, and CBR (California Bearing Ratio) tests to evaluate the soil's bearing capacity. The variations in biochar and cement addition were: 5% biochar with 5% cement, 5% biochar with 6% cement, 5% biochar with 7% cement, and 5% biochar with 8% cement. The research results indicate that the addition of biochar to peat soil stabilization mixtures using cement significantly increases the CBR value. Specifically, adding 8% cement and 5% biochar to peat soil was able to increase the CBR value by up to 9% from the original soil's CBR of 2.2%. Therefore, it can be concluded that the combination of biochar and cement can transform peat soil into a usable subgrade for road construction.

Keywords: Road Construction, Subgrade, Peat Soil, Soil Stabilization, Biochar, Cement

Submitted: 1 July 2025 - Revised: 10 July 2025 - Accepted: 30 July 2025

1. Introduction

One of the significant development initiatives underway in Indonesia is in the transportation sector, specifically the construction of roads. The most crucial part of road construction is the type of soil used as the subgrade, as this layer supports all overlying loads, both static and dynamic. In practice, technical problems related to soil are frequently encountered in the field. One type of soil that is particularly unfavorable for road construction is peat soil. Peat soil often fails to meet the physical and technical requirements for construction work due to its exceptionally high water content and compressibility, coupled with low bearing capacity. Nevertheless, for various reasons and considerations, construction projects on peat deposits are often unavoidable, particularly for road development in regions such as Sumatra, Kalimantan, and Papua .

The estimated area of peat soil in Central Kalimantan is approximately 3 million hectares, making it one of the largest peat ecosystems in Indonesia. Peat in Central Kalimantan typically consists of deep peat, exceeding 3 meters in thickness. A portion of this peatland has been degraded by drainage, land conversion, and forest fires, leading to significant carbon emissions. Peat has the capacity to absorb and trap large amounts of carbon dioxide (CO_2), thus playing a crucial role in climate change mitigation. The condition of peat soil significantly impacts road construction on Kalimantan Island, where roads often traverse vast peatlands. Many sections of these roads are in poor condition due to surface settlement. To address this, a special road pavement construction method is required for these areas. Road construction on peat soil faces several geotechnical challenges, including embankment stability, substantial embankment settlement, and insufficient bearing capacity to withstand applied loads. If not properly handled, such subgrade conditions will adversely affect the road body and accelerate road deterioration. For road embankments, stability analysis, bearing capacity, and settlement analysis are essential to ensure that the desired embankment height for the road body does not experience further settlement after construction is completed.

In civil engineering, improving the properties of peat soil is typically done through soil stabilization. In principle, soil stabilization aims to enhance the quality of poor soil or to further improve already adequate soil. Peat soil exhibits characteristics such as high organic content, susceptibility to significant settlement when exposed to water, and shrinkage upon drying. One method for stabilization involves compaction of peat soil that has achieved stability with high California Bearing Ratio (CBR) and shear strength values when its optimum moisture content is met during compaction [4]. Soil stabilization is critical for any construction project where the existing soil has unfavorable characteristics, such as peat soil [5]. Efforts in soil stabilization and improvements in construction techniques are essential to ensure that roads in peat regions are functional and durable. Soil stabilization is the process of physically, chemically, or mechanically modifying or treating soil to enhance its properties, making it stronger, more resistant to erosion, and suitable for various constructions like roads, airport runways, and other structures. The objectives of soil stabilization are to increase soil strength and durability, prevent significant volume changes, reduce erosion, and extend the lifespan of structures built upon it. Stabilizing peat soil for infrastructure poses unique challenges because peat is inherently soft and prone to degradation.

Mechanically, soil stabilization is achieved by controlling soil particle gradation followed by compaction. Stabilization using additive materials involves adding the chosen additive and then performing compaction. Various types of soil additives are available in Indonesia, including Portland cement, asphalt, sodium chloride, paper mill waste, fertilizer factory waste (gypsum), sulfuric acid, lignin, and others. One interesting innovation that can be used to stabilize peat soil is the use of biochar. Biochar is essentially charcoal made from biomass, derived from plant-based materials and agricultural waste, hence the name biochar. Biochar improves the physical properties of soil by absorbing water, thereby reducing runoff and nutrient leaching. Additionally, biochar can amend soil structure, texture, porosity, and aggregates.

In recent years, research on the utilization of biochar as a soil stabilizing material has gained increasing attention. Biochar is a solid carbonaceous material produced from the pyrolysis of biomass under oxygen-limited conditions[8]. This material is known for its unique physical and chemical properties, such as high specific surface area, good porosity, and adsorption capability[9]. In the context of peat soil stabilization, biochar is expected to contribute to reducing moisture content, increasing shear strength, and stabilizing organic matter. Several initial studies have demonstrated biochar's potential in improving the mechanical properties of soil, including clayey and sandy soils[10],[11]. Even though cement and biochar show individual potential as stabilizers, research on the combination of biochar and cement for peatland stabilization is still relatively limited, especially within the context of specific peat conditions in Indonesia. A primary challenge in stabilizing peat with cement is the interaction between cement and peat's organic matter, which can inhibit the cement hardening process from occurring optimally[[12]. This is where biochar's role becomes interesting, as its properties allow it to bind water and potentially modify the peat's micro-environment, which in turn could influence cement hydration reactions

The combination of biochar and cement in peat soil stabilization offers a unique synergy: cement provides the necessary mechanical strength, while biochar helps improve the soil's physical properties and reduce environmental impact. The use of biochar is also believed to reduce the amount of cement required in stabilization, leading to a more sustainable solution. Soil stabilization of peat using biochar and cement has been demonstrated by Ritter et al, where biochar derived from wood and leaves showed potential to reduce cement usage in peat soil stabilization and significantly increase the strength and stiffness of peat after stabilization with cement. This research focuses on using biochar combined with cement to enhance the subgrade bearing capacity in road construction. The biochar utilized in this study is produced from agricultural waste, specifically coconut shells, which are abundant in the Sampit area of East Kotawaringin Regency. The results of this research are expected to lead to a stabilization method that not only improves the mechanical performance of the soil but also contributes to climate change mitigation through reduced carbon emissions and enhanced carbon storage capacity in the soil.

2. Research Methods

This research employs an experimental method, involving the mixing of peat soil, cement, and biochar with varying additive ratios. The study will be conducted over a 10-month period, from January 2025 to june 2025. The primary objective of this research is to analyze the utilization of biochar in enhancing the stability of peat soil using cement for road construction subgrades, and to assess the reduction in carbon footprint. The peat soil samples will be collected from Jalan Anggrek, Kereng Bangkirai District, Palangka Raya City, Central Kalimantan Province, at coordinates (-2.2794833, 113.9086968).

e-ISSN: 2723-3944

Figure 1. Peat Soil Extraction Location

2.1. Peat Soil Pysical Characteristics Testing

Before stabilization, the original peat soil underwent physical characteristic testing, including: water content determination, specific gravity, unit weight determination, fiber size distribution analysis, and fiber content determination. The peat soil samples were collected in a disturbed state without any special treatment.

2.2. Biochar Production

The raw material for the biochar is coconut shell waste, which is abundantly produced in the coastal area of Ujung Pandaran, East Kotawaringin Regency. This location is approximately 80 km south of Sampit city center, with coordinates (-3.1640689986795882, 112.92960692364882).

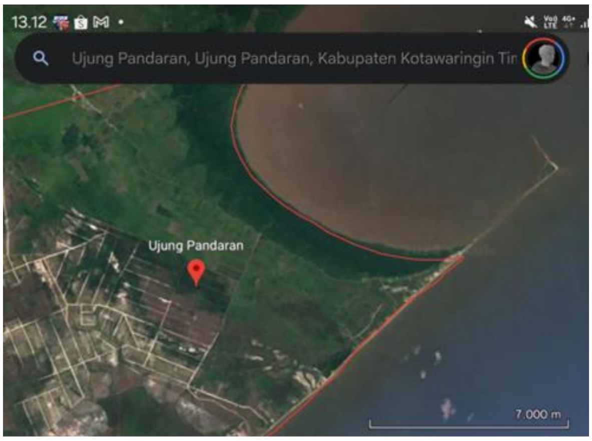

Figure 2. Coconut Shell Harvesting Location Map

Biochar production was carried out at the Environmental Engineering Laboratory of Universitas Muhammadiyah Palangkaraya (UMPR) on Jl. RTA, Palangkaraya City, Central Kalimantan Province.

2.3. Peat Soiul Mechanical Testing

Mechanical testing of peat soil aims to analyze both the original peat soil and peat soil with added biochar and cement. After characterization, the peat soil proceeded to the next stages of testing, namely compaction and bearing capacity (CBR) tests. The mixing of cement and biochar with peat soil was performed at the Geotechnical Engineering Laboratory of Universitas Muhammadiyah Palangkaraya. The tests conducted were compaction testing[17] and soaked CBR testing[18]. The addition of cement and biochar to peat soil was done to achieve a laboratory bearing capacity (CBR) value that meets the requirements for a subgrade, which is 3-7%. The variations in biochar and cement addition were: 5% biochar with 5% cement, 5% biochar with 6% cement, 5% biochar with 7% cement dan 5% biochar with 8% cement.

Preliminary tests were previously conducted on peat soil stabilization with the addition of 5% cement and varying biochar percentages of 5%, 6%, and 7%. The test results indicated that these combinations did not provide a significant increase in the soil bearing capacity (CBR) value. Therefore, further variations were performed by maintaining the biochar content at 5% and varying the cement content to 5%, 6%, 7%, and 8% to evaluate the effect of increased cement proportion on the peat soil's CBR value.

2.4. Data Analysis

The collected data will be analyzed using an experimental quantitative method to test the effectiveness of peat soil stabilization. This approach will allow for direct testing of the mechanical properties of peat soil after stabilization using a combination of cement and biochar. The focus of this approach is to measure the increase in bearing capacity after stabilizing the peat soil with cement and biochar.

Quantitative Data

1. **Compaction Test:** The soil density obtained after compaction will be analyzed to observe the increase in soil bearing capacity.
2. **Compressive Strength Test:** The CBR test results from each mixture will be compared to identify the most effective mixture for improving soil strength.

This research design focuses on direct laboratory testing to measure the effectiveness of peat soil stabilization using a combination of coconut shell waste biochar and cement, with the hope of developing a more efficient and environmentally friendly method for infrastructure construction in peatlands.

3. Results and Discussion

The soil samples tested were obtained from Campus II of Universitas Muhammadiyah Palangkaraya. Geotechnical laboratory tests at Universitas Muhammadiyah Palangkaraya were conducted under two conditions: testing of peat soil and testing of soil with added cement and coconut shell biochar. For both conditions, tests were performed to determine the characteristics of the peat soil, encompassing both physical and mechanical properties. The following sections will detail the results obtained from these physical and mechanical soil tests.

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3.1. Original Soil Water Content

Water content is defined as the ratio of the weight of water in the original soil to the weight of oven-dried soil. The test specimens used in this experiment were peat soil samples collected in a disturbed state. The results obtained from the laboratory tests are presented in Table 1

Table 1. Test Results for Initial Water Content of Peat Soil

Original Soil Water Content			
Cup Number	1	2	3
Cup Weight (gr)	9.90	9.78	9.47
Cup Weight + wet ground (gr)	19.33	19.61	37.49
Cup Weight+ dry soil (gr)	11.35	11.10	36.13
Wet Ground Weight	7.98	8.51	1.36
Dry Soil Weight (gr)	1.45	1.32	26.66
Water Weught (gr)	7.98	8.51	5.10
Water Content (%)	550.34	644.70	596.60
Average Water Content (%)		597.21	

From Table 1, the water content values were found to be 550.34% for sample 1, 644.70% for sample 2, and 596.60% for sample 3. This gives an average water content of 597.21% for the three samples. Based on the classification of peat maturity levels, this moisture content indicates that the peat soil taken from the Universitas Muhammadiyah Palangkaraya Campus 2 location falls into the fibric peat category. This type of peat has a low decomposition rate and high water retention capacity, generally exhibiting a moisture content of > 580% [19][20]

3.2. Water Content

Water content is the ratio of the weight of water the peat soil to the weight of oven-dried peat soil. The test specimens used in this experiment were peat soil samples collected in a disturbed state. The results obtained from the laboratory tests are presented in Table 2

Table 2. Peat Soil Water Content Test Results

Original Soil Water Content			
Cup Number	**1**	**2**	**3**
Cup Weight (gr)	9.92	9.30	9.78
Cup Weight + wet soil (gr)	23.47	23.50	24.43
Cup Weight+ dry soil (gr)	20.16	20.21	20.92
Wet Soil Weight	3.31	3.29	3.51
Dry Soil Weight (gr)	10.24	10.91	11.14
Water Weught (gr)	3.31	3.29	3.51
Water Content (%)	32.32	30.16	31.51
Average Water Content (%)		31.33	

From Table 2, the water content values were determined to be 32.32% for sample 1, 30.16% for sample 2, and 31.51% for sample 3. This yields an average water content of 31.33% across the three samples. Based on these values, several environmental factors around Campus II of Universitas Muhammadiyah Palangkaraya likely influence the water content.

3.3. Unit Weight

Soil bulk density testing carried out with the aim of obtaining soil index parameters, which help determine the overall density of the peat soil, including its air voids and water content. This test was performed on the peat soil samples. Soil bulk density testing is carried out on peat soil in Table 3.

Table 3. Peat Soil Content Weight Test Results

Content Weight			
Ring Number	**1**	**2**	**3**
Ring Weight (gr)	47.65	47.65	47.65
Ring Diamter (cm)	6.3	6.3	6.3
Ring Height (cm)	1.92	1.92	1.92
Ring Area (cm^2)	31.57	31.57	31.57
Ring Volume (cm^3)	59.821	59.821	59.821
Ring Weight+wet ground (gr)	108.410	109.070	108.360
Wet Ground Weight (gr)	60.760	61.420	60.710
Content Weight (gr/cm^3)	1.16	1.027	1.015
Average Content Weight (gr/cm^3)		1.02	

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3.4. Specific Gravity

The specific gravity test for peat soil aims to obtain soil index parameters that functionally relate to the air, water, and solid particle phases within the soil. This specific gravity test was conducted using two methods: on peat soil and on peat soil with added cement and biochar. For peat soil testing with several variations of cement and biochar content were tested. The specific gravity test results are presented in Table 4.

Table 4. Test Results for Peat Soil Specific Gravity and Cement With Added Biochar

Variation	Number of Samples	Gs (%)	Avarage Gs (%)
Peat Soil	1	1.63	1.63
	2	1.63	
Peat Soil + Cement 5% + Biochar 5%	1	1.56	1.56
	2	1.56	
Peat Soil + Cement 6% + Biochar 5%	1	1.57	1.49
	2	1.42	
Peat Soil + Cement 7% + Biochar 5%	1	1.50	1.47
	2	1.51	
Peat Soil + Cement 8% + Biochar 5%	1	1.48	1.45
	2	1.43	

From Table 4, the specific gravity **(Gs)** of peat soil was found to be 1.63. For soil with added cement + biochar (5% + 5%, 6% + 5%, 7% + 5%, and 8% + 5% respectively), the Gs values obtained were 1.63, 1.56, 1.49, 1.47, and 1.45, respectively. A decrease in specific gravity (Gs) was observed when peat soil was mixed with cement and biochar, where an increased proportion of cement actually resulted in a lower Gs value. This phenomenon is attributed to the interaction between cement and organic matter in the peat, which inhibits the hydration process from occurring optimally. Additionally, the initial reaction between cement and organic compounds produces a porous and lightweight bond structure, causing the mixture's volume increase to be disproportionate to the added solid mass. Consequently, the total specific gravity of the mixture decreases even when the amount of cement is increased.

3.5. Fber Size Distribution

The fiber size distribution test was conducted to determine the composition of soil particle sizes. This test is used to ascertain the distribution and gradation of peat soil fibers, which helps in understanding the soil's physical characteristics and how they influence various aspects such as its water retention capacity, fertility, and structural stability. This test was performed on the peat soil samples. The results for the fiber size distribution are presented in Table 5.

Table 5. Peat Soil Content Weight Test Results

Number	Diameter (mm)	Fiber Weight (gram)	Fiber %
8	2.36	3.94	3.94
20	0.84	43.19	43.19
pan		52.87	52.87
		100	100

3.6. Fiber Content

The primary purpose of the fiber content test for soil is to determine the organic fiber content within the soil, especially in peat soil. This test is used to classify peat types based on their fiber content. The results from the sieve analysis are presented in Table 6. Based on the results in table 6, the soil at Campus II of Universitas Muhammadiyah Palangkaraya can be classified as fibric peat.

Table 6. Fiber Content Test Results

Fiber Content				
Sample Number				
A	Dry Fiber Weight	Wr	Gr	11.84
	Initial Dry Fiber Weight	Ws	Gr	15.57
	Water Content	w	gr	31.51
	(Wr/Ws)x100%			76,04

3.7. *Compaction (*Proctor Standart)

The optimum moisture content obtained from the standard Proctor compaction test will be used in the CBR test. In this test, the amount of water added to both the peat soil and the peat soil with cement and biochar additives is the same.

Table 7. Compaction Calculation Results (Proctor Standard)

Variation	Test Number	Mold Volume	(gr)	Wet Soil Weight (gr)	Water Weight (gr)	Dry Soil Weight (gr)	Water Content (%)	γ_{zav}
0.0%	I	902.75	785.00	0.83	2.93	4.42	66,.9	0.78
	II	902.75	788.50	0.83	4.89	7.13	68.58	0.77
	III	902.75	808.00	0.85	3.75	5.30	70.75	0.76
	IV	902.75	805.00	0.85	5.93	7.88	75.25	0.73
	V	902.75	852.00	0.90	4,19	5.36	78.17	0.72
5% + 5%	I	902.75	887	0.94	6.04	8.26	73.12	0.73
	II	902.75	996.5	1.05	7.24	8.97	80.71	0.69
	III	902.75	1047.5	1.11	7.87	9.06	86.87	0.66
	IV	902,.75	1031	1.09	8.72	9.38	92.96	0.64
	V	902.75	1030.5	1.09	7.48	7.08	105.65	0.59
6% + 5%	I	902.75	833	0.88	8.23	8.23	72.66	0.72
	II	902.75	1033.5	1.09	8.38	8.38	77.33	0.69
	III	902.75	1014	1.07	8.52	8.52	82.86	0.67
	IV	902,75	998.5	1.05	8.73	8.73	90.15	0.64
	V	902,75	958	1.01	5.68	5.68	95.60	0.61
7% + 5%	I	902,75	795.5	0.88	5.93	9.14	64.88	0.76
	II	902,75	879	0.97	6.61	9.26	71.38	0.72
	III	902,75	924.5	1.02	7.24	9.16	79.04	0.69
	IV	902,75	924.5	1.02	5.71	6.74	84.72	0.66
	V	902,75	877.5	0.97	7.13	7.87	90.60	0.64
8% + 5%	I	902,75	773	0.82	5.60	10.57	52.98	0.82
	II	902,75	909	0.96	4.47	6.86	65.16	0.75
	III	902,75	985.5	1.04	6.78	9.28	73.06	0.70
	IV	902,75	983.5	1.04	7.35	8.92	82.40	0.66
	V	902,75	925	0.98	7.93	8.80	90.11	0.63

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From the test data above, a graph can be created for the Standard Proctor test, which compares the water content with the dry unit weight of the soil. The comparison graph showing this relationship can be seen below.

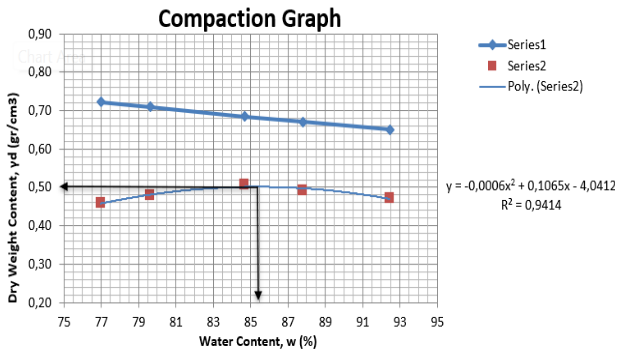

Figure 3. Compaction Graph (Proctor Standard) Of Peat Soil

From Figure 3, which shows the compaction of peat soil without additives, the peat soil compaction curve yields a maximum dry density of 0.50 gr/cm^3 at an optimum moisture content of 85.5%. Meanwhile, the Zero Air Voids (ZAV) curve shows a difference in dry density of 0.18 gram/cm^3. This indicates that the peat soil still has the potential to become more compact.

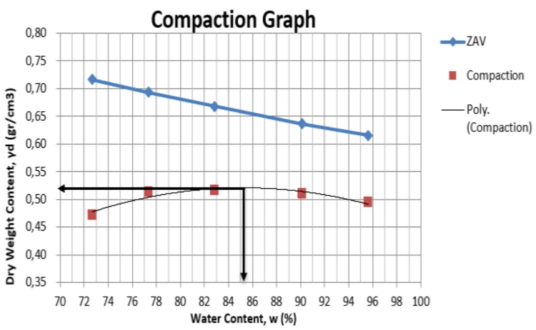

Figure 4. Compaction Graph (Proctor Standard) Of Peat Soil And Soil With 6% Cement + 5% Biochar

From Figure 4, which illustrates the compaction of peat soil with 6% cement and 5% biochar, the peat soil compaction curve yielded a maximum dry density of 0.53 gr/cm^3 at an optimum moisture content of 85.3%. Meanwhile, the Zero Air Voids (ZAV) curve showed a difference in dry density of 0.14 gram/cm^3. This indicates that the peat soil still has the potential to become more compact

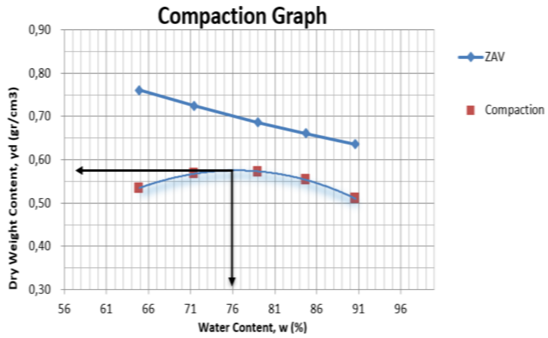

Figure 5. Compaction Graph (Proctor Standard) Of Peat Soil And Soil With 7% Cement + 5% Biochar

From Figure 5, which illustrates the compaction of peat soil with 7% cement and 5% biochar, the peat soil compaction curve yielded a maximum dry density of 0.58 gr/cm^3 at an optimum moisture content of 75.9%. Meanwhile, the Zero Air Voids (ZAV) curve showed a difference in dry density of 0.11 gram/cm^3. This indicates that the peat soil still has the potential to become more compact.

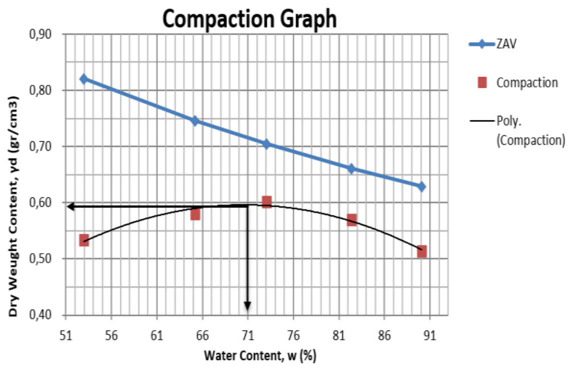

Figure 6. Compaction Graph (Proctor Standard) Of Peat Soil And Soil With 8% Cement + 5% Biochar

From Figure 6, which illustrates the compaction of peat soil with 8% cement and 5% biochar, the peat soil compaction curve yielded a maximum dry density of 0.59 gr/cm^3 at an optimum moisture content of 71.0%. Meanwhile, the Zero Air Voids (ZAV) curve showed a difference in dry density of 0.11 gram/cm^3. This indicates that the peat soil still has the potential to become more compact.

Based on these graphs, the optimum water content (Wopt) and maximum dry weight volume (γd) are produced, which can be seen in Table 8 below.

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Table 7. Results of Optimum Water Content (ωopt) and Dry Unit Weight (γd) Compaction (Proctor Standard)

Varitation	ω_{opt} (%)	γd (gr/cm³)
Original Soil	85.5	0.50
Original Soil + cement 5%+ biochar 5%	87.8	0.58
Original Soil +cement 6%+ biochar 5%	85,3	0.53
Original Soil + cement 7%+ biochar 5%	75,9	0.58
Original Soil + cement 8%+ biochar 5%	71,0	0.59

From Table 7, the optimum moisture content (ωopt) for the original soil was found to be 85,5% with a dry unit weight of 0.50 g/cm³. After adding 5% cement + 5% biochar, the optimum moisture content increased to 87.8% with a dry unit weight of 0.58 g/cm³. For additions of 6% cement + 5% biochar, 7% cement + 5% biochar, and 8% cement + 5% biochar, the optimum moisture content decreased to 85,3%, 75,9%, and 71,0%, respectively. The corresponding dry unit weights for these mixtures also changed to 0.53 g/cm³, 0.58 g/cm³, and 0.59 g/cm³, respectively. Observing the dry unit weight values for the original soil and with the additions of 5% cement + 5% biochar, 6% cement + 5% biochar, 7% cement + 5% biochar, and 8% cement + 5% biochar, the values obtained show an increase. This occurs because the cement + biochar significantly influence the soil volume, leading to an increase in dry unit weight (calculated based on the dry mass of soil per unit volume of soil).

3.8. Cailfornia Bearing Ratio (CBR)

California Bearing Ratio (CBR) testing is carried out with the aim of determining the soil bearing capacity value in maximum density. In this test, the optimum water content obtained from the compaction test (proctor standard) is used.

Table 8 Results of Calculation of Dry Unit Weight of CBR Before Soaking

Variation	Number of Collisions	Mold Volume (cm3)	Before Soaking					
			Wet Soil Weight (gr)	Wet Content Weight (kg/cm³)	Water Weight (gr)	Dry Soil Weight (gr)	Content Water (%)	Dry Content Weight (gr/cm³)
	10		1.679	0.819	6.88	7.28	94.51	0.421
	25	2.187	1.799	0.878	4.1	7.86	52.16	0.577
0.0%	56		1.734	0.846	3.32	6.75	49.19	0.567
	10		1.477	0.721	2.25	5.91	38.07	0.522
	25	2.187	1.684	0.822	3.88	7.16	54.19	0.533
5% + 5%	56		1.857	0.906	3.19	6.34	50.32	0.642
	10		1.810	0.883	7.16	8.24	86.89	0.473
	25	2.187	1.986	0.969	7.96	8.36	95.22	0.496
6% + 5%	56		1.675	0.817	6.94	9.53	72.82	0.473
	10		1.702	0.83	6.98	10.22	69.3	0.493
	25	2.187	2.277	1.111	7.1	7.75	91.61	0.580
7% + 5%	56		2.308	1.126	6.14	7.03	87.34	0.601
	10		1.499	0.731	5.68	9.22	61.61	0.453
	25	2.187	1.697	0.828	3.87	6.31	61.33	0.513
8% + 5%	56		1.865	0.91	2.77	4.67	59.31	0.571

Table 9 Results of Calculation of Dry Unit Weight of CBR After Soaking

Variation	Number of Collisions	Mold Volume (cm3)	After Soaking					
			Wet Soil Weight (gr)	Wet Content Weight (kg/cm³)	Water Weight (gr)	Dry Soil Weight (gr)	Content Water (%)	Dry Content Weight (gr/cm³)
	10		2.379	1.161	6.69	4.63	144.49	0.475
	25	2.187	2.211	1.079	7.27	7.78	93.44	0.558
0,00%	56		2.285	1.115	6.57	7.65	85.88	0.600
	10		2.132	1.04	5.78	5.63	102.66	0.513
	25	2.187	2.305	1.125	6.23	6.96	89.51	594
5% + 5%	56		2.402	1.172	5.24	6.35	82.52	0.642
	10		2.009	0.98	9.65	9.06	106.51	0.475
	25	2.187	2.166	1.057	10.01	9.46	105.81	0.514
6% + 5%	56		2.103	1.026	9.08	10.47	86.72	0.55
	10		2.029	0.99	9.45	9.57	98.75	0.498
	25	2.187	2.360	1.152	8.73	6.57	132.88	0.495
7% + 5%	56		2.460	1.2	7.44	10.52	70.72	0.703
	10		2.282	1.114	8.54	7.04	121.31	0.503
	25	2.187	2.379	1.161	7.79	7.29	106.86	0.561
8% + 5%	56		2.469	1.205	7.42	7.36	100.82	0.600

Based on the results of the original soil penetration data and soil with the addition of 5% cement + 5% bicohar, 6% cement + 5% bicohar, 7% cement + 5% bicohar, and 8% cement + 5% bicohar, the CBR value of each sample can be determined through the compaction graph connected to the CBR graph, which can be seen in the following image.

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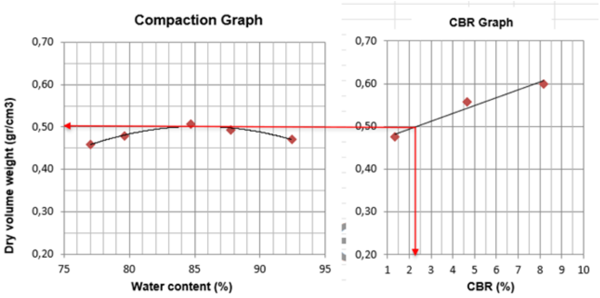

Figure 8. Peat soil CBR price

Figure 8 shows the regression relationship between the CBR value and the dry unit weight of the soil from the compaction results with variations of blows of 10, 25, and 56 times, namely 0.47, 0.56 and 0.60. This regression curve is adjusted to the maximum dry unit weight value obtained from the standard compaction test at the same blow variation, namely 0.5. Based on the regression analysis, the CBR value obtained was 2.2% at maximum density conditions, which reflects the bearing capacity of the stabilized peat soil under optimum compaction conditions..

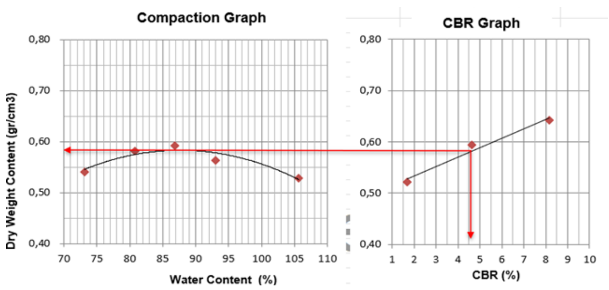

Figure 9. CBR price chart of peat soil with 5% cement + 5% biochar

In Figure 9, the regression relationship between the CBR value and the dry unit weight of the soil from the results of compaction with variations of blows of 10, 25, and 56 times is shown, namely 0.52, 0.59 and 0.64. This regression curve is adjusted to the maximum dry unit weight value obtained from the standard compaction test at the same variation of blows, namely 0.58. Based on the regression analysis, a CBR value of 4.6% was obtained at maximum density conditions, which reflects the bearing capacity of the stabilized peat soil under optimum compaction conditions.

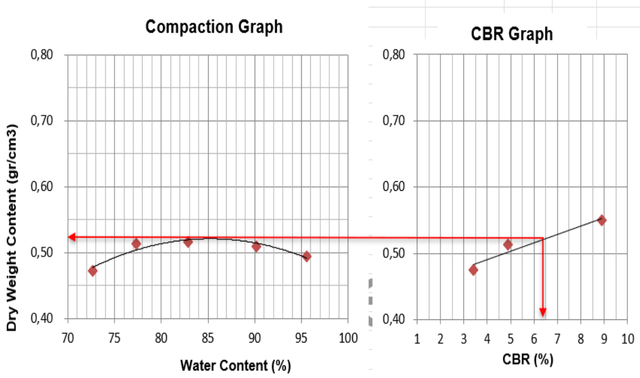

Figure 10. CBR price chart of peat soil with 6% cement + 5% biochar

In Figure 10, the regression relationship between the CBR value and the dry unit weight of the soil from the results of compaction with variations of blows of 10, 25, and 56 times is shown, namely 0.47, 0.51 and 0.55. This regression curve is adjusted to the maximum dry unit weight value obtained from the standard compaction test at the same variation of blows, namely 0.53. Based on the regression analysis, a CBR value of 6.4% was obtained at maximum density conditions, which reflects the bearing capacity of the stabilized peat soil under optimum compaction conditions.

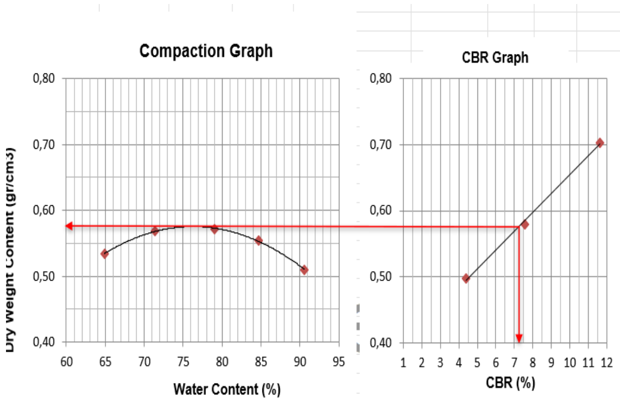

Figure 11. CBR price chart of peat soil with 7% cement + 5% biochar

In Figure 11, the regression relationship between the CBR value and the dry unit weight of the soil from the results of compaction with variations of blows of 10, 25, and 56 times is shown, namely 0.50, 0.58 and 0.70. This regression curve is adjusted to the maximum dry unit weight value obtained from the standard compaction test at the same variation of blows, namely 0.58. Based on the regression analysis, a CBR value of 7.2% was obtained at maximum density conditions, which reflects the bearing capacity of the stabilized peat soil under optimum compaction conditions.

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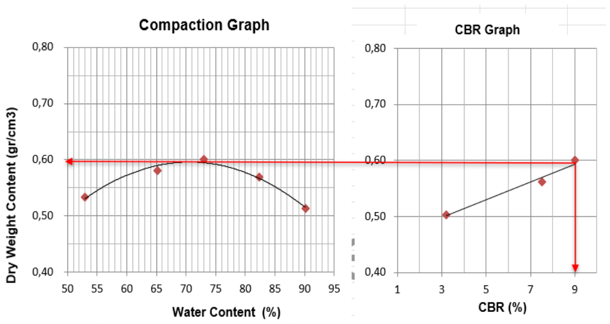

Figure 12. CBR price chart of peat soil with 8% cement + 5% b

Figure 12 shows the regression relationship between the CBR value and the dry unit weight of the soil from the results of compaction with variations of blows of 10, 25, and 56 times, namely 0.50, 0.56 and 0.60. This regression curve is adjusted to the maximum dry unit weight value obtained from the standard compaction test at the same variation of blows, namely 0.59. Based on the regression analysis, a CBR value of 9.00% was obtained at maximum density conditions, which reflects the bearing capacity of the stabilized peat soil under optimum compaction conditions.

Based on the graph, it is evident that each addition of biochar increases the CBR value. The CBR value of the original soil was 2.20%. After the addition of 5% cement + 5% biochar, 6% cement + 5% biochar, 7% cement + 5% biochar, and 8% cement + 5% biochar, the CBR values increased to 4.60%, 6.40%, 7.20%, and 9.00% respectively. It can be concluded that there is an increase in the CBR value with each variation of cement addition, which can help maximize the soil's bearing capacity.

3.9. Comparison of CBR Test Results For Original Soil vs Soil With Added Cement + Biochar

Based on the CBR test results, the original soil yielded a value of 2,2%. Following the addition of cement + biochar (5% cement + 5% biochar, 6% cement + 5% biochar, 7% cement + 5% biochar, and 8% cement + 5% biochar), the CBR values increased to 4.60%, 6.40%, 7.40%, and 9.00% respectively. Below is a comparison table showing the CBR values for both the original soil and the soil with added cement + biochar, along with the implications of these CBR values for their usage.

Table 10. Comparison of CBR Test Results of Original Soil and Soil with Biochar Addition

Number	Test Type	Code	CBR (%)	Use
1	Peat Soil	PS	2.20	*Subgrade*
2	Peat Soil + Cement 5% + Biochar 5%	PS S5%+B5%	4.60	*Subgrade*
3	Peat Soil + Cement 6% + Biochar 5%	PS S6%+B5%	6.40	*Subgrade*
4	Peat Soil + Cement 7% + Biochar 5%	PS S7%+B5%	7.40	*Sub base*
5	Peat Soil + Cement 8% + Biochar 5%	PS S8%+B5%	9.00	*Sub base*

Based on the results of the comparison of CBR test values with original soil and soil with the addition of cement + biochar in table 11, it can be seen in diagram 13 below.

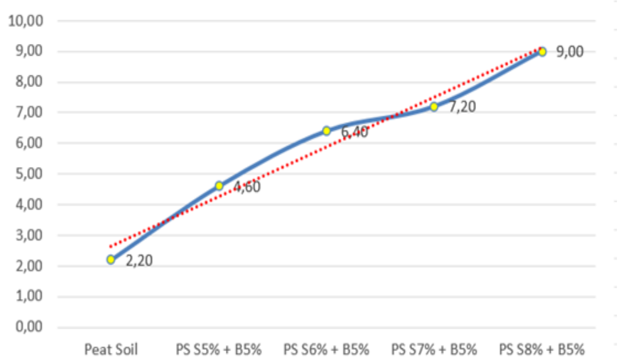

Figure 13. Comparison diagram of CBR test values of original soil with the addition of cement + biochar

Based on the diagram in Figure 12, it's clear that the addition of cement + biochar can significantly affect the CBR value of the original soil. The diagram shows a continuous rise in CBR from 7% cement + 5% biochar up to 8% cement + 5% biochar. Specifically, the addition of 7% cement + 5% biochar and 8% cement + 5% biochar can upgrade the function of the original soil from a subgrade to a subbase. Furthermore, using this cement + biochar mixture can reduce the need for aggregate materials in road repairs and can be directly utilized as aggregate material in peat soil. Overall, the test results demonstrate that adding cement + biochar effectively increases the CBR value of the original soil.

e-ISSN: 2723-3944

4. Conclusion

The conclusions drawn from this research are as follows:

1. The water content of peat soil in Palangka Raya City is 597.21%. Based on its water absorption capacity, Palangka Raya's peat soil is classified as moderate, with a water holding capacity between 300% and 800% namely peat with a low decomposition rate and high water retention capacity, which generally has a moisture content of > 580%"
2. The specific gravity of peat soil from Palangka Raya City is 1.63%, and its fiber content is 76.043%. This classifies the peat soil as fibric (raw peat).
3. Bearing Ratio (CBR) value. The CBR value of the original soil was 2.2%. With the first variation (peat soil + 5% cement + 5% biochar), the CBR value increased to 4.6%. For the second variation (peat soil + 6% cement + 5% biochar), the CBR value was 6.4%. The third variation (peat soil + 7% cement + 5% biochar) resulted in a CBR value of 7.2%. Finally, the fourth variation (peat soil + 8% cement + 5% biochar) achieved a CBR value of 9%.
4. Adding 8% cement and 5% biochar to peat soil was able to increase the CBR value up to 9%, enabling the soil to function effectively as a subgrade in accordance with technical specifications

5. Suggestion

Based on the findings of this study, the following recommendations are made:

1. Based on the research results, the combination of 8% cement and 5% biochar significantly increased the CBR value of peat soil to 9%. Therefore, this combination is recommended as an alternative stabilization method for peat soil, suitable for subgrade layers in light to moderate traffic road construction.
2. For future research, it is suggested to explore a wider range of cement and biochar content variations to identify the optimal composition that yields maximum strength with better material efficiency.
3. Further studies should also include long-term durability tests against weather changes, water immersion, and wet-dry cycles to ensure soil stability in tropical environmental conditions.
4. Beyond the CBR test, it is advisable to conduct additional tests such as Unconfined Compressive Strength (UCS) tests, permeability tests, and microscopic examinations (SEM/EDS) to better understand the particle bonding mechanisms within the stabilized mixture.

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This work was supported and partially funded by Universitas Muhammadiyah Kalimantan Timur (UMKT) grant no PPI-001.

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e-ISSN: 2723-3944