Journal of Materials Engineering, Structures and Computation

Journal homepage: www.nipesjournals.org.ng

Enhancement of the Bearing Capacity of Lateritic soil Using Pulverized Cow Bone

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ARTICLE INFORMATION

Article history:
Received 16 May 2023
Revised 24 May 2023
Accepted 26 May 2023
Available online 12 June 2023

Keywords:
Pulverized cow bone, bearing capacity, soil stabilization, maximum dry density, soil improvement.

https://doi.org/10.5281/zenodo.8028566

ISSN-2682-5821/

ABSTRACT

This study investigated the use of pulverized cow bone (PCB) as a means of enhancing the bearing capacity of lateritic soil. A series of laboratory tests were conducted, including compaction tests, soaked and unsoaked CBR tests, and penetration tests on soil-PCB mixtures. The results showed that the addition of PCB to lateritic soil improved the maximum dry density, decreased the optimum moisture content, and increased the unsoaked and soaked CBR values of the soil. The maximum unsoaked CBR value of the soil-PCB mixture was 8.39%, which was obtained with a proportion of 94:6 (soil:PCB) while the maximum soaked CBR value of the soil-PCB mixture was 51.8%, which was obtained with a proportion of 8% PCB. Furthermore, the penetration test results revealed that the addition of PCB increased the load-bearing capacity of the soil. Therefore, it can be concluded that the use of PCB as a stabilizing agent has the potential to enhance the bearing capacity of lateritic soil and could be a sustainable and cost-effective method for soil stabilization in civil engineering applications.

1. Introduction

Lateritic soil is a common type of soil found in tropical and subtropical regions, particularly in Africa, South America, and Asia. They are widely used for construction purposes due to their availability and low cost [1,2]. However, their relatively low bearing capacity often poses a challenge for engineering applications, leading to soil stabilization techniques being necessary for construction purposes [3,4].

Soil stabilization is an important technique used to improve the engineering properties of soil. The use of natural or waste materials as additives for soil stabilization has gained attention in recent years due to their low cost and environmental benefits. Various soil stabilization techniques have been used to improve the engineering properties of lateritic soils, including the use of lime, cement, and fly ash, among others [5]. However, the cost and sustainability of these materials have been questioned, leading to the exploration of alternative soil stabilizers. One of these alternative materials is pulverized cow bone.

Recently, researchers have explored the use of animal bones as a sustainable and cost-effective alternative for soil stabilization [6]. One such animal bone material is pulverized cow bone. Cow bones have a high calcium carbonate content, which has been found to improve the strength and stiffness of soils when mixed with them [6,7]. Several studies have investigated the use of pulverized cow bone as a soil stabilizer for improving the geotechnical properties of various soil types [8].

However, limited research has been conducted on the use of pulverized cow bone for enhancing the bearing capacity of lateritic soil. This study aims to investigate the potential of pulverized cow bone for improving the bearing capacity of lateritic soils sourced from Uwheru Town in Delta Central Region of Delta State, Nigeria.
The bearing capacity of soil is a critical factor that determines the load-carrying capacity of soil for supporting structures and infrastructures. It is a vital aspect of geotechnical engineering design. Recently, researchers have delved into the possibility of using atypical materials like animal bones for stabilizing soil. Studies have shown that the addition of pulverized animal bones to soil can significantly improve its geotechnical properties, including the bearing capacity [6,7]. Therefore, the utilization of pulverized cow bone, which presents an eco-friendly and cost-effective option, is a promising area of exploration for enhancing the bearing capacity of lateritic soil.
Pulverized Cow Bone (PCB), is a byproduct of the meat processing industry. It is considered abundant and low cost due to its availability as a byproduct of the livestock industry and its minimal processing requirements [9,10]. Previous studies have revealed that incorporating PCB into soil can enhance its stability and strength [11,12]. For instance, reference [13] explored the use of cow bone powder as a soil stabilizer and found that it considerably increased the soil's compressive strength. Similarly, reference [14] observed that the introduction of cow bone to soil enhanced its rigidity and reduced its deformation. However, in order to fully comprehend the influence of cow bone on the bearing capacity of lateritic soil, particularly the lateritic soil obtained from Uwheru Town, a more extensive investigation is required. Therefore, this study aims to address this and provide valuable insights into the subject matter.

2. Material and methods

2.1 Lateritic soil

For this research, disturbed soil samples were obtained from Uwheru Town in the Delta Central Region of Delta State, Nigeria. The samples were collected at a depth of 1000mm below the natural ground level at each sampling site [15]. The pits were excavated using diggers and shovels, and the soil specimens were carefully collected and tightly sealed in polyethylene bags to ensure minimal moisture exchange. Each sample was appropriately labeled with its corresponding location. Subsequently, the samples were left to dry naturally in order to eliminate initial moisture content present in the soil.

2.2 Pulverized cow bone

Cow bones utilized in the study were sourced from an abattoir located on Eburu Street, off Eboh Road, Okumagba layout, Warri, Delta State. The bones were left to sun-dry for a few months to eliminate surplus fats and oils, making them amenable to being ground into a fine powder. The powdered cow bone was subsequently placed in an airtight container to shield it from moisture before testing.
The samples were air-dried and then pulverized to pass through a 2 mm sieve. Each soil sample was subdivided into 5 parts, with each part receiving a single dose of 0, 2, 4, 6, and 8% of PCB by weight. The soil sample's moisture content and maximum dry density were determined. The following laboratory tests were performed on both the raw soil samples and their pulverized cow bone stabilized counterparts, excluding the preliminary grain size analysis test:

2.2 Methods

The soil samples collected were divided into five equal parts. Each part was treated with a different dosage of pulverized cow bone (PCB) by weight, ranging from 0 to 8%. The moisture content and maximum dry density of the soil samples were then measured to prepare them for the California bearing ratio (CBR) test. The following laboratory tests were carried out on both the untreated soil samples and the soil samples stabilized with pulverized cow bone:

- Compaction test

- Moisture content.
- California Bearing Ratio (CBR)

2.2.1 Compaction test:

The compaction test is a technique utilized to determine the optimal moisture content required for a soil sample to attain its maximum dry density. It is performed to analyze the moisture-density correlation of compacted lateritic soil. Initially, air-dried lateritic soil passing through No. 4 sieve and of a known weight is compacted in a cylindrical mold of standard dimensions with a compactive effort of specific weight and frequency at a specific moisture content. The estimated moisture content is recorded, and specimens are prepared accordingly. The moisture content is subsequently varied, with an increment not exceeding four percent, and the process is repeated for various moisture contents while determining the dry densities for each. A compaction curve is then plotted based on the graphical correlation of the dry density to moisture content. The peak point of the curve and its corresponding moisture content are referred to as the maximum dry density (MDD) and optimal moisture content (OMC), respectively.

2.2.2 Moisture content test:

The moisture content test was conducted to determine the quantity of water in the lateritic soil sample relative to its oven dry mass. Moisture content is an important property of soil as it affects various aspects such as permeability, compaction, particle size, and more. The percentage of moisture content was determined following the procedure outlined in ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil Aggregate Mixtures. In some cases, the moisture content of soil is used to establish the relationship between soil properties and behavior. In fine-grained soils, the consistency is highly dependent on the moisture content and it is also used to express the phase relationships of air, water, and solids in a specified mass of soil.

To perform this test, the moisture can and cover number were recorded. The mass of the unfilled, clean, and dry moisture can with its cover (MC) was weighed and recorded. Wet soil was then placed into the moisture can and the cover securely fastened. The mass of the moisture can (now containing the wet soil) with the cover (MCMS) was determined and recorded. The cover was removed and the moisture can (containing the wet soil) was placed in a drying oven set at 105°C. The can was left overnight and then removed from the oven. The cover on the moisture can was carefully removed and replaced using gloves, and allowed to cool to room temperature. The mass of the moisture can and cover (containing the dry soil) (MCDS) was then determined and recorded. Finally, the water/moisture content of the laterite was determined.

2.2.3 California bearing ratio test:

The California Bearing Ratio (CBR) test is used to determine the strength of a subgrade, sub base, or base course material for road construction. The test is based on the penetration resistance of a standard plunger with a diameter of 50mm and a penetration of 2.5mm. The resistance is then expressed as a percentage of the known resistance of the plunger to 2.5mm in penetration in crushed aggregate (taken as 13.2kN).

To perform the CBR test, a representative sample of the material to be tested, usually passing through a 20mm sieve and retained on a 4.75mm sieve, is thoroughly mixed with water to achieve the optimal moisture content (OMC) which is recorded. The prepared sample is then compacted into a cylindrical mold with a standard height and diameter of 150mm and 100mm, respectively.

The compaction is carried out in layers of approximately 50mm, with 56 blows of a 4.5kg hammer delivered to each layer through a free fall of 450mm. After compaction, the top surface is trimmed, and the specimen is weighed and placed in a soaking tank for a period of four days to ensure complete saturation. After the soaking period, the specimen is placed in a CBR apparatus, and the plunger is lowered into the specimen at a rate of 1.25mm/minute. The load required to achieve a penetration of 2.5mm is recorded and used to calculate the CBR value of the sample. Figure 1 shows the equipment used for the test.

Figure 1: CBR Loading Machine

3. Results and Discussion

3.1 Water/moisture content

Table 1 shows the results of the water content test carried out on three different samples of the natural soil. Each trial was conducted on a different container with a unique number. The weight of each container with the wet soil (W1) and the weight of the container with the dry soil (W2) were measured and recorded. From this, the weight of the water (Ww) was determined by subtracting the weight of the dry soil (Ws) from the weight of the wet soil (W1 - W2).
The water content (Wc) was then calculated as a percentage by dividing the weight of water (Ww) by the weight of dry soil (Ws) and multiplying by 100. The water content values for each trial are 17.64%, 16.99%, and 17.29%, respectively. The average water content for the three trials is 17.31%. These findings suggest that the soil sample contains a moderate amount of water, implying that the soil is not overly dry, which is beneficial for workability and compaction purposes. This indicates that the soil has retained a certain level of moisture, which can contribute to its cohesion and shear strength [16,17].

Table 1: Water content for natural lateritic soil

Water content result			
Trial No:	1	2	3
Container Number	61	38	29
Weight of container (Wo) in g	32.66	28.42	30.36
Weight of container + wet soil (W_1) in g	63.87	60.29	66.58
Weight of container + dry soil (W_2) in g	59.19	55.66	61.24
Weight of water (W_w) in g	4.68	4.63	5.34
Weight of dry soil (Ws) in g	26.53	27.24	30.88
Water content (Wc) = (W_w / Ws) x 100 %	17.64	16.99	17.29
Average Water content = 17.31 %.			

3.2 Compaction

Table 2 shows the results of a compaction test conducted on natural lateritic soil. The table includes four trials, with each trial having specific parameters measured. The parameters measured include the mass of wet soil in the mould (Mo) in kg, weight of wet soil (Ws) in N, moist unit weight of soil (Mu), water content (W/C) in %, volume of mould (Vm) in m^3, and dry unit weight of soil (Du) in kN/m^3.

The results show that as the water content of the soil increases, the moist unit weight of soil also increases. The maximum dry density (MDD) of the soil was found to be 18.6 KN/m^3, which is the highest dry density achieved during the test. The optimal moisture content (OMC) was found to be 14%, which is the moisture content at which the maximum dry density was achieved.

Overall, the table provides information on the compaction characteristics of the natural lateritic soil, including the relationship between water content and unit weight, as well as the MDD and OMC of the soil.

Table 2: Compaction results for natural lateritic soil.

Trial No	Mass of wet soil in mould (kg)	Weight of wet soil (N)	Moist unit weight of Soil	Water Content (%)	Volume of Mould (m^3)	Dry unit weight of soil (kN/m^3)
1	1.84	18.02	19.09	8.00	9.44×10^{-4}	17.68
2	1.93	18.94	20.06	11.00	9.44×10^{-4}	18.07
3	2.04	20.01	21.20	14.00	9.44×10^{-4}	18.60
4	2.25	22.05	23.36	17.00	9.44×10^{-4}	19.97
MMD = 18.6 kN/ m^3				OMC = 14.00 %		

3.3 California bearing ratio

3.3.1 Effect of PCB stabilization on CBR (un-soaked) of soil sample

Table 3 shows the California Bearing Ratio (CBR) values of the natural soil and the soil mixed with various percentages of pulverized cow bone (PCB). The unsoaked CBR test was performed on the samples, and the penetration and load values were recorded. The Load value of the natural soil ranges from 15.00kg to 128.13kg for penetration values of 0.50 mm to 10.00 mm.

The addition of PCB improves the load value of the soil. At 2% PCB content, the CBR value increased by 10kg to 78kg compared to the natural soil. The highest improvement was observed at 6% PCB content, with a CBR value increase of up to 93%. However, the CBR value decreased slightly at 8% PCB content. The result indicates that the addition of PCB to the lateritic soil can significantly improve its bearing capacity.

The increase in the CBR value can be attributed to the interaction between the abundant calcium content in the PCB and the fine particles of the soil as documented in previous studies [15]. Furthermore, the formation of cementitious compounds between the PCB and the calcium compounds present in the soil samples can also contribute to the overall improvement [18]. However, it is crucial to consider that excessive addition of PCB beyond the peak CBR values may result in a decline in CBR. This decline can be linked to the excessive PCB content, which has the potential to alter the particle distribution and compaction characteristics of the soil, thereby negatively impacting its load-bearing capacity [18,19].

Table 3. Results of PCB on unsoaked soil CBR.

S/N	Penetration (mm)	Load value (kg)				
		Natural soil	Natural soil + 2% PCB	Natural soil + 4% PCB	Natural soil + 6% PCB	Natural soil + 8% PCB
1	0.50	15.00	25.00	35.00	35.00	30.00
2	1.00	30.00	40.00	50.00	57.50	50.00
3	2.00	42.50	50.00	62.50	72.50	75.00
4	2.50	52.50	70.00	80.00	95.00	92.50
5	3.00	65.00	87.50	95.00	117.50	110.00
6	3.00	70.00	90.00	112.50	125.00	130.00
7	3.50	75.00	105.00	125.00	135.00	130.00
8	4.00	85.00	117.50	140.00	145.00	142.50
9	4.50	87.50	125.00	143.75	153.13	146.80
10	5.00	93.75	134.38	156.25	162.50	158.25
11	5.50	96.88	140.63	162.50	171.88	162.50
12	6.00	101.25	143.75	168.75	175.00	168.75
13	6.50	106.25	159.38	181.25	184.38	175.00
14	7.00	109.38	162.50	184.38	196.88	184.38
15	7.50	112.50	171.88	193.75	212.50	190.62
16	8.00	115.63	178.13	201.88	215.63	200.63
17	8.50	118.75	187.50	212.50	225.00	209.38
18	9.00	121.88	193.75	218.75	231.25	215.63
19	9.50	125.00	200.50	225.00	237.50	221.88
20	10.00	128.13	206.25	231.25	246.88	228.13

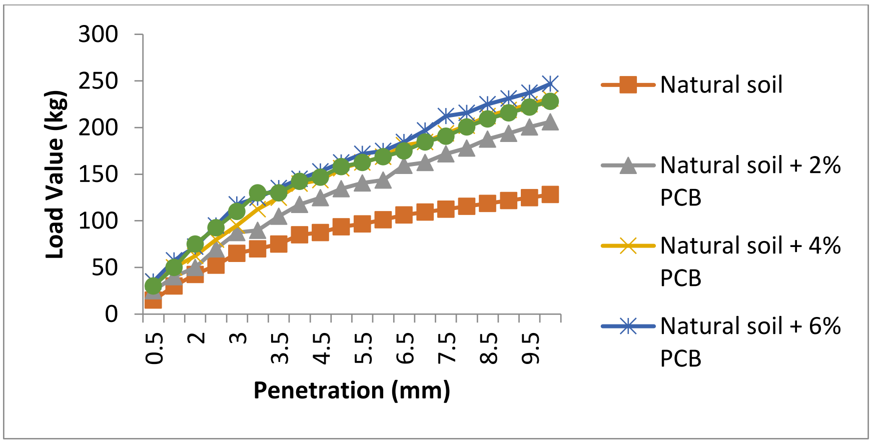

Figure 2: Load and Penetration of soil stabilized with different proportion of PCB under un-soaked conditions

Table 4 presents the results of the CBR (California Bearing Ratio) tests conducted on soil samples mixed with pulverized cow bone (PCB) at different proportions. The proportion of soil to bone ash (PCB) is indicated in the "Proportion Soil: Bone Ash" column, while the corresponding un-soaked CBR values are presented in the "Un-soaked CBR (%)" column.

Sample No. 1, with a soil to bone ash proportion of 100:0, achieved an un-soaked CBR value of 4.67%. As the proportion of bone ash increased in subsequent samples, there was a noticeable improvement in the un-soaked CBR values. Sample No. 2, with a proportion of 98:2, exhibited a CBR value of 6.20%, indicating a slight enhancement compared to the previous sample. This trend continued with Sample No. 3, 96:4, demonstrating an un-soaked CBR of 6.93%, and Sample No. 4, 94:6, showing an un-soaked CBR of 8.39%.

However, it is important to note that Sample No. 5, with a proportion of 92:8, displayed a slight decrease in the un-soaked CBR value to 8.02%. This suggests that further increases in the bone ash content may not result in a significant improvement in the un-soaked CBR.

Overall, the test results indicate that the addition of pulverized cow bone to the soil mixture has the potential to enhance the un-soaked CBR, thereby improving the bearing capacity of the lateritic soil.

Table 4: CBR (Un-soaked) test results for soil: PCB mix

Sample No.	Proportion Soil: Bone Ash	Un-soaked CBR (%)
1	100:0	4.67
2	98:2	6.20
3	96:4	6.93
4	94:6	8.39
5	92:8	8.02

3.3.2 Effect of PCB stabilization on CBR (Soaked) of soil sample.

Table 5 results for soaked soil CBR show that the addition of pulverized cow bone (PCB) has improved the bearing capacity of the lateritic soil. As the percentage of PCB increases from 2% to 8%, the load value required to penetrate the soil also increases for each penetration depth, indicating an increase in the soil's strength.

For example, at a penetration depth of 5mm, the load value for natural soil is 69.00 kg, while the load values for natural soil mixed with 2%, 4%, 6%, and 8% PCB are 92.00 kg, 101.20 kg, 121.90 kg, and 112.50 kg, respectively (Figure 3). This suggests that the addition of 6% PCB gives the highest load value for this penetration depth.

Overall, the results show that the addition of PCB has a positive impact on the lateritic soil's strength, and the optimal percentage of PCB varies depending on the penetration depth. The study concludes that pulverized cow bone is a promising material for improving the bearing capacity of lateritic soil.

Table 5: Results of PCB on Soaked soil CBR

S/N	Penetration (mm)	Load value (kg)				
		Natural soil	Natural soil + 2% PCB	Natural soil + 4% PCB	Natural soil + 6% PCB	Natural soil + 8% PCB
1	0.50	9.2	13.8	18.40	23.00	25.30
2	1.00	20.70	27.60	32.20	34.50	36.80
3	2.00	29.90	39.10	46.00	57.50	50.60
4	2.50	39.10	57.50	62.10	73.60	66.70
5	3.00	48.3	64.40	71.30	87.40	78.20
6	3.00	52.9	69.00	80.50	96.60	85.10
7	3.50	55.20	75.90	87.40	103.50	92.00
8	4.00	59.80	80.50	92.00	108.10	98.90
9	4.50	64.40	87.40	96.60	115.00	105.80
10	5.00	69.00	92.00	101.20	121.90	112.50
11	5.50	73.60	94.30	105.80	126.50	117.30

12	6.00	78.20	101.20	110.40	135.70	124.20
13	6.50	82.80	103.50	115.00	142.60	131.10
14	7.00	85.10	108.10	119.60	149.50	135.70
15	7.50	89.70	112.70	126.50	156.40	140.30
16	8.00	94.30	115.00	131.10	164.80	147.20
17	8.50	96.60	117.30	135.70	167.90	151.80
18	9.00	98.90	119.60	140.30	174.80	156.40
19	9.50	101.20	124.30	147.20	181.70	158.70
20	10.00	103.50	126.50	149.50	184.00	161.00

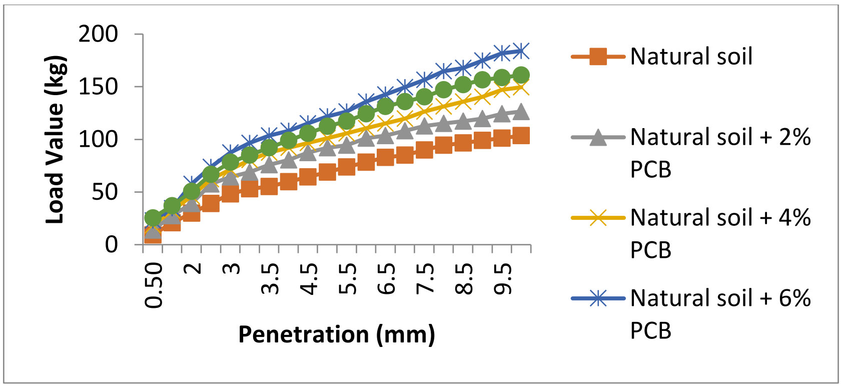

Figure 3. Load and Penetration of soil stabilized with different proportion of PCB under soaked conditions

Table 6 presents the results of soaked CBR (California Bearing Ratio) tests conducted on different samples of soil mixed with varying proportions of pulverized cow bone (PCB). It shows the effect of incorporating different amounts of PCB into the soil on the soaked CBR values. The table shows that the soaked CBR values increase as the proportion of PCB in the mixture increases, except for sample 4, where the CBR value is slightly lower than sample 5. Sample 1, which contains 100% soil and no PCB, has the lowest soaked CBR value of 2.84%. Sample 2, which contains 2% PCB, has a soaked CBR value of 3.78%, which is higher than sample 1. Sample 3, with 4% PCB, has a soaked CBR value of 4.16%, which is higher than samples 1 and 2. Sample 4, with 6% PCB, has a soaked CBR value of 5.03%, which is the highest CBR value of all the samples. However, sample 5, with 8% PCB, has a slightly lower soaked CBR value of 4.52%.
Overall, the results suggest that the addition of PCB to soil can improve the soaked CBR of the soil-PCB mixture, with the maximum improvement observed at 6% PCB proportion. The higher CBR values with increasing PCB proportions indicate an increased ability of the soil to withstand load and deformation under soaked conditions. This information is valuable for applications where soil stability and performance in wet conditions are crucial, such as road construction or foundation engineering projects.

Table 6. CBR (Soaked) test results for soil – PCB mixture

Sample No.	Proportion Soil: Bone Ash	Un-soaked CBR (%)
1	100:0	2.84
2	98:2	3.78
3	96:4	4.16
4	94:6	5.03
5	92:8	4.52

4. Conclusion

Based on the findings of this study, it can be concluded that incorporating pulverized cow bone (PCB) significantly improves the bearing capacity of lateritic soil samples. The California Bearing Ratio (CBR) values demonstrate a consistent increase as the percentage of PCB increases, both for unsoaked and soaked soil conditions. The highest CBR value is achieved at a PCB proportion of 6% for both unsoaked and soaked soil. This improvement in CBR can be attributed to the high calcium and mineral content present in PCB, which enhances the soil's strength. These results indicate that the addition of PCB is an effective and cost-efficient method for stabilizing lateritic soil in sub-base and sub-grade materials used in road construction. Additionally, the compaction test results can provide useful information for designing foundations and other structures on the soil.

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