



Waste Engine Oil Contamination Effect on the Consistency, Compaction and CBR Behaviour of Niger Delta Lateritic Soils

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ABSTRACT

Used engine oil, commonly called condemned oil, is routinely discarded on open ground around vehicle repair workshops in Nigeria, where it can seep into the lateritic soils that form roadbeds and embankments. This study examined how waste engine oil changes the index and strength properties of two lateritic soils from Bori (Khana LGA) and Bomu (Gokana LGA), Rivers State. Both soils are poorly graded sands containing 2–3% fines and classify as AASHTO A-2-5 in their natural state. Samples were mixed with 0, 2, 4, 6, 8 and 10% oil and tested for liquid limit, plastic limit, maximum dry density (MDD) and California bearing ratio (CBR) in unsoaked and soaked conditions, following British Standard and AASHTO procedures. Linear regression was used to relate each property to oil content. Raising contamination from 0 to 10% reduced the liquid limit by 34% (Bori) and 40% (Bomu), increased the plastic limit by 37% and 35%, and lowered MDD by 14% and 20%. Both soils became non-plastic at roughly 2–3% oil. Unsoaked CBR fell from 13.58% to 5.22% (Bori) and from 10.58% to 3.63% (Bomu), while soaked CBR fell from 9.94% to 3.70% and from 8.75% to 2.81%. Linear models gave coefficients of determination between 0.96 and 1.00. The results show that even modest oil contents of 2–4% weaken these lateritic materials, and that oil-contaminated laterites should not be used as subgrade or pavement fill without remediation or stabilization. Practical screening guidance for highway engineers is offered.

Keywords: waste engine oil; lateritic soil; soil contamination; California bearing ratio; Atterberg limits; compaction; subgrade; regression analysis

1. INTRODUCTION

Lateritic soils are the most widely used natural road-building material in tropical regions, serving as embankment fill, subgrade, and, with suitable processing, sub-base and base courses [1], [2]. Their ready availability near the point of construction makes them economical, and their behaviour under compaction and soaking has been studied extensively [2], [3]. In Nigeria, national specifications place minimum soaked CBR requirements on materials that increase from subgrade through sub-base to base, so any process that lowers the bearing capacity of a laterite directly affects its eligibility for use in a pavement structure [4].

The condition of these soils at the time of construction is not always pristine. Rivers State lies in the Niger Delta, a region with heavy industrial and petroleum-related activity and a long record of hydrocarbon release into the environment [5]. Beyond large-scale spills, a more diffuse and less documented source of contamination is the disposal of used lubricating oil. A single engine oil change produces several litres of waste oil, and in many Nigerian towns this is drained onto bare ground beside mechanic workshops, poured into drains, or used to suppress dust and weeds. Used oil is a mixture of base oil, degraded additives, and metals and combustion by-products accumulated during service, and it is considered a hazardous waste in many jurisdictions [6], [7]. Where workshop plots, roadside parking areas and borrow pits are located on lateritic ground, the soil that is later excavated, hauled and compacted for road works may therefore carry unknown quantities of oil.

The geotechnical consequences of petroleum contamination have been examined for a range of soil types. Studies of crude oil in clayey and sandy soils [8], oil in basaltic residual soil [9], motor oil in over-consolidated clay [10], oil-contaminated Kuwaiti sand [11], and oil-contaminated fine-grained soils [12], [13] have reported that contamination alters consistency limits, compaction characteristics, shear strength and compressibility, with the magnitude and direction of change depending on the soil mineralogy, grain size, oil type and oil content [8]–[13]. A general trend of reduced density and reduced strength at higher oil contents is commonly reported, although the response of plasticity is more variable and depends on whether the soil is clay-rich or granular [8]–[13]. Investigations into the remediation of fuel-oil-contaminated soil have also shown that stabilization can partly restore engineering behaviour [14]. Work on Nigerian soils includes the effect of oil contamination on the consistency and compaction of soils [15] and the potential reuse of oil-contaminated soil in construction [16]. More recent work has examined the stabilization of crude-oil-contaminated clay with cement and lime [17]. However, most of this body of work addresses either clays, sands, or crude oil, whereas lateritic road-foundation soils contaminated specifically with used engine oil have received comparatively little systematic attention, and studies that report soaked and unsoaked CBR side by side, the measures most relevant to highway design, are especially scarce.

This gap matters for practice. A highway engineer who encounters a laterite with an oil odour or visible staining on site has little published guidance on whether the material is still suitable for use as subgrade, and by how much its properties may have changed. The question is not only academic: the CBR value is the basic input to pavement thickness design [18], and an over-estimate of subgrade strength leads directly to under-designed pavements that deform or fail early.

The present study therefore investigates the effect of waste engine oil on two lateritic soils from Khana and Gokana Local Government Areas of Rivers State. The specific objectives were to: (i) characterize the natural soils by particle-size distribution, Atterberg limits and compaction; (ii) determine how oil content between 0 and 10% affects liquid limit, plastic limit, maximum dry density and unsoaked and soaked CBR; (iii) develop regression relationships between each property and oil content; and (iv) interpret the results in terms of their implications for highway subgrade design and for the screening of potentially contaminated borrow material.

The novelty of the work lies in its focus on used engine oil rather than crude oil, in its use of two locally important lateritic soils, and in the combined treatment of consistency, compaction and both CBR conditions within one experimental programme that is analysed using simple predictive equations suitable for site screening.

2. MATERIALS AND METHODS

2.1 Materials

i. Lateritic soils. Disturbed samples of lateritic soil were collected from two locations in Rivers State: Bori town in Khana Local Government Area and Bomu town in Gokana Local Government Area. The samples were transported to the laboratory in sealed bags, air-dried, and broken down with a wooden mallet to avoid altering the grain sizes. For convenience the two soils are referred to as the Bori and Bomu laterites.

ii. Waste engine oil. Used engine oil, commonly referred to as condemned oil, was collected from a car mechanic workshop in Bori, Rivers State. It was drained from vehicles during routine servicing and was used without further treatment, so that it represents the material that is actually discarded on workshop grounds.

2.2 Preparation of Contaminated Specimens

The air-dried soils were mixed with waste engine oil at 0, 2, 4, 6, 8 and 10% by weight of soil to give six contamination levels for each soil. The oil was added gradually and the mixture was kneaded until visually uniform. The 0% specimens served as the control for each soil. Testing was carried out on each oil content in the same sequence for both soils so that results can be compared directly.



2.3 Laboratory tests

All laboratory tests were carried out in line with the relevant British Standard [19] and AASHTO [20] procedures, as follows.

i. Particle-size distribution. Dry sieve analysis was performed on the natural soils using sieves from 2.36 mm down to 75 μm , with the material retained in the receiver recorded separately. The coefficient of uniformity, $C_u = D_{60}/D_{10}$, was read from the particle-size distribution curve, where D_{60} and D_{10} are the particle diameters corresponding to 60% and 10% passing. The soils were classified using the AASHTO system [20] and, for the coarse-grained fraction, the Unified Soil Classification System [21].

ii. Atterberg limits. The liquid limit and plastic limit were determined for the natural soils and for each contaminated mixture, and the plasticity index was computed as the difference between the two. For the contaminated mixtures, a plasticity index was recorded as negative whenever the measured plastic limit exceeded the measured liquid limit; these cases are interpreted as non-plastic.

iii. Compaction. The compaction test was performed at standard energy, with each layer compacted using 25 blows of a 2.5 kg hammer falling through a height of 300 mm. For each oil content the moisture–density relationship was established, and the maximum dry density (MDD) was recorded. The optimum moisture content (OMC) was recorded for the natural soils only.

iv. California bearing ratio. CBR tests were carried out on specimens prepared at each oil content, both without soaking (unsoaked CBR) and after soaking in water (soaked CBR). The CBR values are expressed as a percentage of the standard crushed-stone load–penetration reference.

2.4 Data analysis

The test data were plotted against oil content for each property: liquid limit, plastic limit, MDD, unsoaked CBR and soaked CBR. Simple linear regression by least squares [22] was used to fit the equation

$$y = a + bx \quad (1)$$

where y is the property of interest, x is the oil content in percent, a is the intercept, which approximates the value for the uncontaminated soil, and b is the slope, which is the average change in the property per percentage point of oil. The goodness of fit was assessed by the coefficient of determination, R^2 . The relative change in each property between 0% and 10% oil was calculated as (value at 10% – value at 0%) divided by the value at 0%. The retention ratio, defined as soaked CBR divided by unsoaked CBR at the same oil content, was also computed to indicate the sensitivity of the contaminated soil to water.

3. RESULTS AND DISCUSSION

3.1 Characteristics of the natural lateritic soils

The particle-size distributions of the two soils are given in Table 1. Both are dominated by sand-sized particles: more than 90% of each sample passes the 850 μm sieve, yet only 2% (Bori) and 3% (Bomu) passes the 75 μm sieve. The transition between 850 μm and 300 μm is sharp, with the percentage passing falling from 94% to 38% in the Bori sample and from 93% to 35% in the Bomu sample, which indicates that most of the material is fine to medium sand in the 0.15–0.85 mm range.

Table 1. Particle-size distribution of the Bori and Bomu laterites

Sieve size	Bori, % passing	Bomu, % passing
2.36 mm	100	100
2.0 mm	99	99



1.18 mm	97	97
850 µm	94	93
300 µm	38	35
212 µm	21	20
150 µm	19	18
75 µm	2	3
Receiver	0	0

The coefficients of uniformity were 2.50 for the Bori soil ($D_{60} = 325 \mu\text{m}$, $D_{10} = 130 \mu\text{m}$) and 3.44 for the Bomu soil ($D_{60} = 413 \mu\text{m}$, $D_{10} = 120 \mu\text{m}$). Both values are below the value of about 6 conventionally required for a well-graded sand, so the soils are poorly graded, uniform sands in the sense of the Unified Soil Classification System [21]. The Bomu soil is slightly coarser in its D_{60} and slightly more widely graded..

The index and compaction properties of the natural soils are shown in Table 2. The liquid limits (44.4% and 42.5%) and plasticity indices (8.1% and 5.4%) show that the fine fraction is of low plasticity. Because fewer than 35% of the material passes the 75 µm sieve, and the liquid limit exceeds 40% while the plasticity index is 10% or lower, both soils fall within the AASHTO A-2-5 group [20], which is rated as excellent to good as subgrade material when uncontaminated. The Bori soil has the slightly higher maximum dry density (1760 against 1740 kg/m³) and the slightly lower optimum moisture content (18% against 19%).

Table 2. Properties of the natural lateritic soils

Property	Bori	Bomu
Liquid limit, %	44.4	42.5
Plastic limit, %	36.3	37.1
Plasticity index, %	8.1	5.4
Maximum dry density, kg/m ³	1760	1740
Optimum moisture content, %	18	19
Coefficient of uniformity, C_u	2.50	3.44
Unsoaked CBR, %	13.58	10.58
Soaked CBR, %	9.94	8.75

The natural unsoaked CBR values of 13.58% and 10.58% and the soaked values of 9.94% and 8.75% place both soils in the range generally associated with fair to poor subgrade material according to the Nigerian specification for subgrade materials $\text{CBR} \geq 10\%$, but they fail to meet the required criteria for subbase materials of $\text{CBR} \geq 30\%$.. The soaked-to-unsoaked ratio is 73% for the Bori soil and 83% for the Bomu soil, so soaking removes a substantial fraction of the strength of the clean soils, which is typical of granular laterites whose strength depends partly on suction and light cementation by iron and aluminium oxides [1], [2].

3.2 Effect of waste engine oil on consistency limits

The liquid limit decreased steadily with oil content in both soils (Table 3). The Bori soil dropped from 44.4% to 29.5% and the Bomu soil from 42.5% to 25.4% as the oil content was increased from 0 to 10%, equivalent to reductions of 33.6% and 40.2%. Most of the reduction takes place early: at 4% oil the liquid limit had already fallen by 15.5% (Bori) and 18.8% (Bomu). The plastic limit moved in the opposite direction, rising from 36.3% to 49.6% (Bori) and from 37.1% to 50.1% (Bomu), increases of 36.6% and 35.0%.

Table 3. Liquid limit, plastic limit and derived plasticity index of the oil-contaminated laterites.

Oil content, %	LL Bori, %	LL Bomu, %	PL Bori, %	PL Bomu, %	PI Bori, %	PI Bomu, %
0	44.4	42.5	36.3	37.1	8.1	5.4
2	42.5	40.2	38.8	39.3	3.7	0.9

4	37.5	34.5	41.5	40.6	-4.0	-6.1
6	34.6	32.8	43.7	44.6	-9.1	-11.8
8	32.7	29.7	46.5	47.2	-13.8	-17.5
10	29.5	25.4	49.6	50.1	-20.1	-24.7

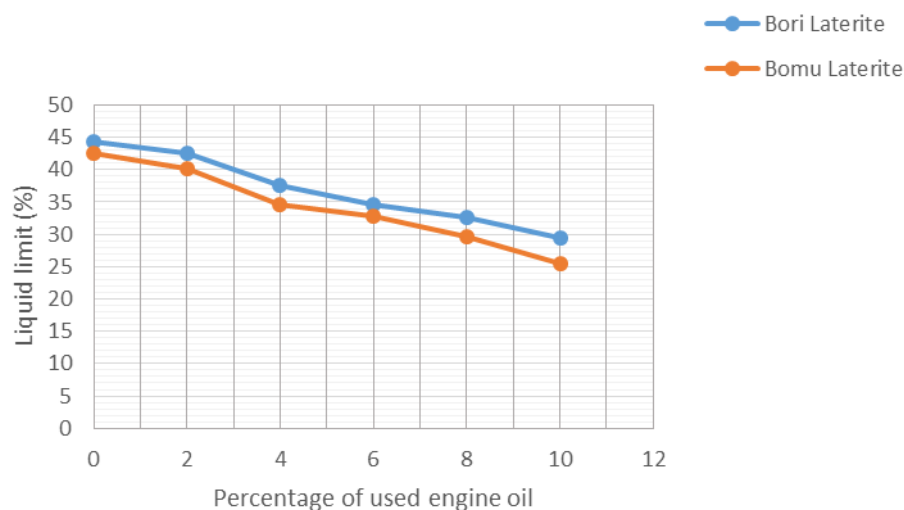


Figure 1. Graph of liquid limit vs used engine oil

The divergence of the two limits has an important consequence for the plasticity index. Beyond about 2–3% oil the plastic limit exceeds the liquid limit, which is not physically meaningful for a plastic soil, and the arithmetic plasticity index becomes negative. Linear interpolation of the fitted lines places the crossover at about 2.9% oil for the Bori soil and 2.0% for the Bomu soil. The correct interpretation is that the contaminated soils behave as non-plastic (NP) beyond these oil contents. The practical implication is that plasticity index, which is routinely used to screen road materials, would classify a heavily contaminated laterite as more favourable than the clean soil, even though its strength has fallen sharply. Plasticity alone is therefore an unreliable screening parameter for oil-contaminated granular soils.

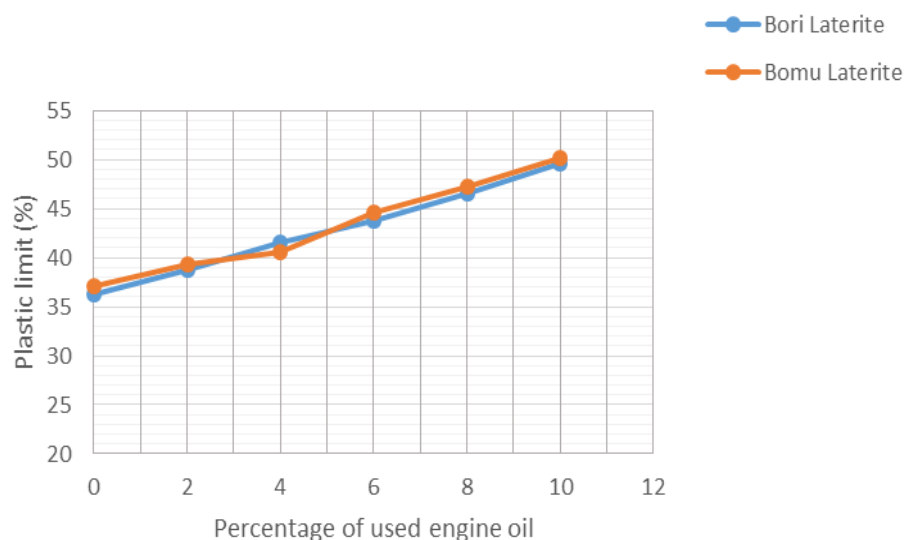


Figure 2. Graph of Plastic limit vs used engine oil

Several mechanisms are plausible, and they are consistent with the explanations offered for oil-contaminated soils elsewhere [8]–[13], [24]. Oil is non-polar and hydrophobic. It coats soil grains and the oxide-rich coatings of laterite particles, reducing the surface available for water adsorption, so less water is needed to bring the soil to the liquid limit; this accounts for the falling liquid limit. At the plastic limit, by contrast, the soil is rolled into threads, and the oil acts as a lubricant that lets the threads hold together and deform without crumbling until a higher total fluid content is reached, so the measured plastic limit rises since the fluid content now includes oil as well as water.

3.3 Effect of waste engine oil on compaction

The maximum dry density decreased with oil content in both soils (Table 4). The Bori laterite lost 240 kg/m³ (13.6%) between 0 and 10% oil, and the Bomu laterite lost 350 kg/m³ (20.1%). At 4% oil the losses were still modest at 3.4% and 6.9%, but the decline accelerates between 4% and 8%. The Bomu soil, which starts from a lower density, is more affected than the Bori soil at every oil level.

Table 4. Maximum dry density of the oil-contaminated laterites.

Oil content, %	MDD Bori laterite (kg/m ³)	MDD Bomu laterite (kg/m ³)
0	1760	1740
2	1750	1670
4	1700	1620
6	1650	1540
8	1580	1460
10	1520	1390

Two mechanisms are likely to act together. First, oil has a much lower density than soil solids, about 0.85–0.9 g/cm³ compared with a typical particle density of 2.6–2.7 g/cm³ for lateritic soils, so a fixed volume of compacted mixture with a larger oil fraction contains less solid mass. Second, the oil film on grain contacts changes the way the soil responds to compaction effort: it can lubricate the grains in a way that would initially help rearrangement, but it also occupies pore space and the non-polar film resists the formation of the water menisci that give moist granular soil part of its compactibility and apparent cohesion [23], [24]. A decline in density with increasing oil content has been reported for several oil-contaminated soils [8]–[13], [15], and the present results agree with that general trend. A reduction in MDD is directly relevant to construction because specifications usually require a minimum percentage of the laboratory maximum density in the field, and a contaminated soil that cannot reach the specified density is likely to have lower stiffness and greater long-term settlement.

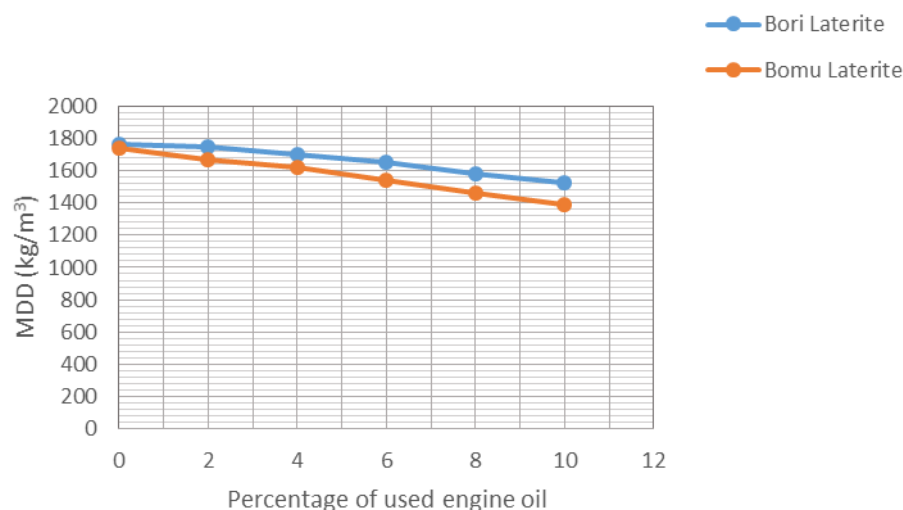


Figure 3. Graph of maximum dry density vs used engine oil

3.4 Effect of waste engine oil on CBR

Both the unsoaked and the soaked CBR fell sharply with increasing oil content (Table 5). Unsoaked CBR decreased from 13.58% to 5.22% in the Bori soil (−61.6%) and from 10.58% to 3.63% in the Bomu soil (−65.7%). Soaked CBR decreased from 9.94% to 3.70% (−62.8%) and from 8.75% to 2.81% (−67.9%). Even at 2% oil the unsoaked CBR decreased by 8.6% (Bori) and 16.0% (Bomu), and at 4% by 24.3% and 29.8%. The soaked CBR at 4% was lower than the natural value by 14.3% for the Bori soil and by 32.6% for the Bomu soil.

Table 5. Unsoaked and soaked CBR of the oil-contaminated laterites, with soaked/unsoaked retention

Oil content, %	Unsoaked CBR Bori, %	Unsoaked CBR Bomu, %	Soaked CBR Bori, %	Soaked CBR Bomu, %	Retention Bori, %	Retention Bomu, %
0	13.58	10.58	9.94	8.75	73.2	82.7
2	12.41	8.89	9.72	7.86	78.3	88.4
4	10.28	7.43	8.52	5.90	82.9	79.4
6	7.68	5.32	6.43	5.17	83.7	97.2
8	6.75	4.73	4.77	3.64	70.7	77.0
10	5.22	3.63	3.70	2.81	70.9	77.4

The retention ratio is informative. It stays between about 71% and 97% across the full range of oil contents and shows no consistent decline with oil, so the soaked-to-unsoaked ratio at 10% oil (71% and 77%) is similar to that of the clean soils (73% and 83%). In other words, oil does not make the soils markedly more sensitive to water in relative terms. The loss of strength is instead a loss of the strength that the soil has in the first place, which is consistent with the hydrophobic film limiting water entry while weakening grain-to-grain contact.

A decrease in CBR is the expected result of the combined effects described above. Lower dry density reduces the number of particle contacts per unit volume; oil on grain surfaces lowers intergranular friction and the apparent cohesion that arises from moisture and sesquioxide bonding; and the oil-filled pores do not generate the suction that supports the penetration resistance of an unsoaked laterite. Reduced shear strength and bearing capacity have been reported for several oil-contaminated soils [8]–[13], and the present results extend that evidence to lateritic road-foundation sands.

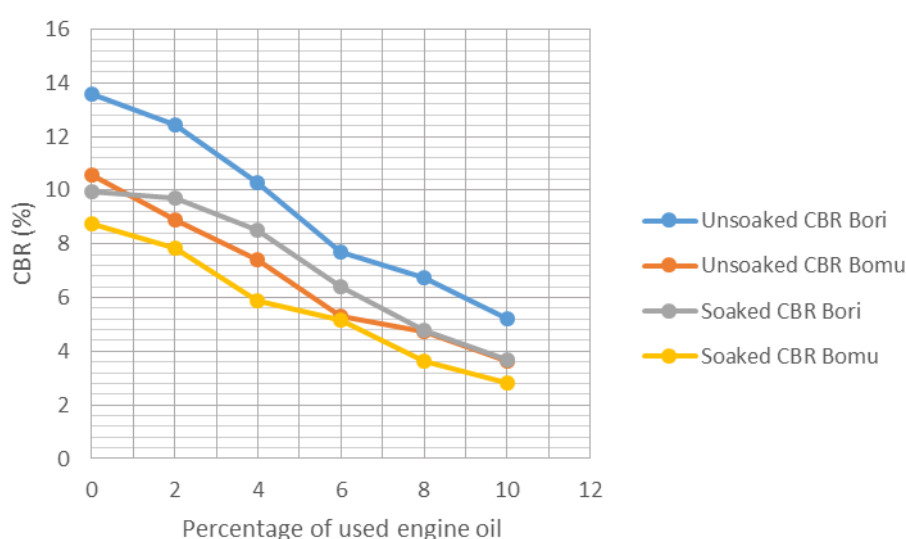


Figure 4. Graph of CBR (unsoaked and soaked) vs used engine oil

3.5 Regression models

Table 6 gives the linear regression equations for each property against oil content x (in percent) fitted over the



0–10% range, together with the coefficient of determination.

Table 6. Linear regression models, $y = a + bx$, for oil contents of 0–10%.

Property	Laterite	Equation	R ²
Liquid limit, %	Bori	$y = 44.50 - 1.526x$	0.984
Liquid limit, %	Bomu	$y = 42.66 - 1.696x$	0.984
Plastic limit, %	Bori	$y = 36.18 + 1.311x$	0.998
Plastic limit, %	Bomu	$y = 36.53 + 1.324x$	0.984
MDD, kg/m ³	Bori	$y = 1785.7 - 25.14x$	0.966
MDD, kg/m ³	Bomu	$y = 1745.7 - 35.14x$	0.996
Unsoaked CBR, %	Bori	$y = 13.70 - 0.877x$	0.984
Unsoaked CBR, %	Bomu	$y = 10.29 - 0.705x$	0.978
Soaked CBR, %	Bori	$y = 10.62 - 0.688x$	0.964
Soaked CBR, %	Bomu	$y = 8.77 - 0.616x$	0.987

All ten fitted relationships show coefficients of determination from 0.964 to 0.998, so a straight line describes the trend in each property adequately over the tested range. The slopes make the comparison between soils clear. Per percentage point of oil, the liquid limit drops by about 1.5 points (Bori) and 1.7 points (Bomu), the plastic limit rises by about 1.3 points in both soils, MDD falls by about 25 kg/m³ (Bori) and 35 kg/m³ (Bomu), unsoaked CBR falls by 0.88 and 0.71 points, and soaked CBR falls by 0.69 and 0.62 points. In absolute CBR points the Bori soil loses more because it starts higher, but in relative terms the Bomu soil loses more in all properties except the plastic limit. A possible explanation, which these data cannot confirm without further tests, is that the coarser and slightly more widely graded Bomu soil has lower natural density and a higher natural optimum moisture content, leaving it with less margin before oil displaces the water that is helping to hold its structure together.

A caution apply to these models. First, with only six oil contents and a single test at each, a high R² shows that the trend is regular, not that the straight line is the true functional form: the MDD of the Bori soil, for instance, declines slowly at first and faster afterwards, suggesting mild curvature.

3.6 Implications for highway engineering practice

The results have four practical implications. First, the subgrade CBR governs pavement thickness [18], and these data show that a laterite with a few percent of oil may lose a quarter or more of its unsoaked CBR (24% to 30% at 4% oil) and as much as a third of its soaked CBR (14% to 33% at 4% oil). A design that assumes the CBR of the clean material could therefore under-estimate the required thickness. Second, at 6% oil the soaked CBR is 6.4% (Bori) and 5.2% (Bomu), and at 10% it is 3.7% and 2.8%, values that are typically regarded as poor subgrade and that would need to be improved or covered by a thick capping layer; none of the contaminated mixtures at 4% or above would be expected to satisfy the soaked CBR requirement that is commonly quoted for lateritic sub-base [4]. Third, because plasticity index falls to non-plastic values while strength declines, index tests alone are not adequate for screening suspect borrow material. Visual and olfactory inspection, a simple oil content check by solvent extraction, and CBR testing on representative samples are all more reliable. Fourth, where contaminated lateritic soil cannot be avoided, the literature suggests that stabilization or modification may recover part of its engineering performance [14], [17], and that industrial by-products have been used to improve weak lateritic and other soils [25]. The effectiveness of such treatments for used engine oil in these two soils has not been tested here and should be a subject of further work.

These findings also have an environmental dimension. Highway agencies in the Niger Delta often source laterite from roadside borrow pits that are close to settlements and workshops, and the screening steps above would add little cost to project preparation while protecting both the pavement and the surrounding environment.



4. CONCLUSIONS

This paper examined the effect of waste engine oil at 0–10% on the index properties, compaction characteristics and CBR of two lateritic soils from Bori and Bomu in Rivers State, Nigeria. The following conclusions can be drawn from the laboratory results.

1. The natural soils are poorly graded sands (C_u of 2.50 and 3.44) containing 2–3% fines, with low-plasticity fines, and classify as AASHTO A-2-5. Their natural MDD is 1760 and 1740 kg/m³ and their natural soaked CBR is 9.94% and 8.75%.
2. Oil contamination reduced the liquid limit linearly, by 33.6% (Bori) and 40.2% (Bomu) at 10% oil, and increased the plastic limit by 36.6% and 35.0%. The soils became non-plastic at about 2–3% oil, so plasticity index is not a dependable indicator of suitability for contaminated granular laterites.
3. The maximum dry density decreased by 13.6% (Bori) and 20.1% (Bomu) at 10% oil, with the Bomu soil more sensitive at every oil content.
4. Unsoaked CBR decreased by 61.6% and 65.7%, and soaked CBR by 62.8% and 67.9%, over the 0–10% range. Losses of about 24–30% of unsoaked CBR were already evident at 4% oil. The soaked-to-unsoaked ratio did not fall systematically with oil content, so the loss of bearing capacity is a loss of absolute strength and not an increased sensitivity to water.
5. Linear regression models described all five properties for each soil with R^2 values between 0.964 and 0.998, giving simple equations for estimating the likely loss of properties within the tested range.
6. For highway practice, laterites suspected of oil contamination should be screened by CBR testing and not by consistency limits alone, and should not be used as subgrade or fill at the contamination levels examined here without remediation or stabilization.

Future work should include shear strength and permeability tests, soils of higher clay content, field-aged contaminated soils, other oil types, and stabilization trials using cement, lime or industrial and agricultural wastes to restore the strength of contaminated laterites.

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