Volume-10 Issue 04, April -2026
ISSN: 2456-9348
Impact Factor: 8.232

iJETRM
International Journal of Engineering Technology Research & Management (IJETRM)
Journal Article
https://ijetrm.com/issue/

EFFECT OF DIESEL OIL CONTAMINATION ON THE GEOTECHNICAL PROPERTIES OF LATERITE SOIL

Enyinnia C.P,
Nnanna A. M,
Ezinne C.F.
Civil Engineering Department,
Federal Polytechnic Nekede, Owerri, Nigeria
Email: nopsoftinc@yahoo.com

ABSTRACT

Laterite soil is extensively used in civil engineering works in tropical regions due to its availability and generally acceptable engineering characteristics. However, increasing hydrocarbon pollution arising from fuel stations, automobile workshops, and industrial activities has raised concerns regarding the suitability of contaminated lateritic soils for construction purposes. This study investigates the effect of diesel oil contamination on the geotechnical properties of laterite soil obtained from Federal Polytechnic Nekede, Nigeria. Laboratory tests were conducted on uncontaminated soil and samples contaminated with varying diesel contents of 2%, 4%, 6%, and 8% by dry weight. The tests included particle size distribution, Atterberg limits, Standard Proctor compaction, and California Bearing Ratio (CBR). Results show that diesel contamination causes a progressive reduction in maximum dry density and CBR, accompanied by noticeable changes in consistency limits and compaction behavior. The CBR value decreased from 49.36% for the natural soil to about 21.23% at higher diesel contents, indicating severe loss of bearing capacity.

Keywords:
Laterite soil, Diesel contamination, Compaction, California Bearing Ratio, Geotechnical properties

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INTRODUCTION

Laterite soil is a residual soil formed under intense weathering in tropical and subtropical environments and is widely used in road construction, embankments, and foundation works. However, increasing dependence on petroleum products has resulted in frequent hydrocarbon contamination of soils, especially diesel oil, which significantly alters soil engineering behavior.

Chemistry and Behavior of Hydrocarbons in Soil

Diesel oil, the contaminant under investigation, is a complex and heterogeneous mixture of hundreds of hydrocarbon compounds, primarily within the C9–C25 carbon range [1]. Its composition includes linear and branched alkanes (paraffins), cycloalkanes (naphthenes), and aromatic hydrocarbons (including polycyclic aromatic hydrocarbons – PAHs), along with additives for performance enhancement [2]. It is classified as a Light Non-Aqueous Phase Liquid (LNAPL) because it is immiscible with water and has a density less than water (typically 0.83–0.85 g/cm^3) [3].

Upon release into the subsurface, LNAPLs like diesel undergo a complex sequence of transport and fate processes:

1) **Infiltration and Distribution:** Diesel migrates vertically through the soil pores under gravity until it encounters a capillary fringe or a low-permeability layer, where it may accumulate and spread laterally [2].
2) **Volatilization:** Lighter, more volatile fractions evaporate into the soil gas, which can reduce the mass of the contaminant but may also pose vapor intrusion risks [4].
3) **Dissolution:** Slightly soluble components, particularly some aromatic compounds like benzene, toluene, ethylbenzene, and xylene (BTEX), can dissolve into the pore water, leading to groundwater contamination [1].
4) **Sorption:** Hydrocarbons can sorb onto the surfaces of soil organic matter and clay minerals, a process that retards their migration but also facilitates their long-term persistence [5].

5) **Biodegradation:** Under suitable aerobic or anaerobic conditions, microorganisms can metabolize hydrocarbons, breaking them down into simpler, less harmful compounds. However, this process is often slow and incomplete for heavier fractions of diesel [4].

The persistence of diesel in the soil environment is high, with residues remaining for decades, continuously posing a threat to both the geotechnical integrity of the soil and the surrounding ecosystem [6].

Mechanisms of Hydrocarbon–Soil Interaction

The deterioration of geotechnical properties due to hydrocarbon contamination is not a singular event but a consequence of several interconnected physicochemical mechanisms operating at the microscale.

Particle Coating and Lubrication:

Diesel oil coats individual soil grains, forming a hydrophobic film. This coating disrupts the natural inter-particle contacts that provide frictional resistance **[7]**. Furthermore, the oil acts as a lubricant, reducing the shear resistance between particles and facilitating particle sliding, thereby decreasing the overall shear strength of the soil mass [8].

Alteration of Soil–Water Interaction and Wettability:

The introduction of a hydrophobic contaminant like diesel fundamentally changes soil wettability, making it more oleophilic and water-repellent [5, 3]. This reduces the soil's affinity for water, directly affecting the Atterberg Limits, and disrupts the formation of capillary menisci responsible for apparent cohesion in unsaturated soils [9, 10].

- **Reduction in Matric Suction:**

Diesel oil interferes with soil–water potential due to its low dielectric constant, reducing the soil's ability to retain water and develop high matric suction, resulting in a net loss of shear strength [9, 11].

- **Chemico-Mineralogical Alterations:**

Hydrocarbons can interact with cementing agents in lateritic soils, leading to the dissolution or weakening of iron and aluminum oxide bonds responsible for soil structure [12]. In clayey soils, non-polar fluids suppress the diffuse double layer, causing particle flocculation and a weaker, more compressible soil fabric [11, 3].

- **Pore Fluid Dielectric Constant Change:**

Water has a high dielectric constant (~80), which supports double-layer development, whereas diesel oil has a very low dielectric constant (~2). This leads to double-layer collapse, clay flocculation, and significant changes in consistency limits and compaction behavior [13, 10].

MATERIALS AND METHODS

Laterite soil was collected from a borrow pit within Federal Polytechnic Nekede at a depth of 1.0–1.5 m. Automotive diesel oil was added at 0%, 2%, 4%, 6%, and 8% by dry weight using a dry contamination technique. Laboratory tests followed relevant ASTM standards.

Research Design

This study employed a quantitative experimental research design. The core methodology involved collecting a representative sample of laterite soil and subjecting it to a series of standardized geotechnical tests in both its natural (uncontaminated) state and after being artificially contaminated with predetermined percentages of diesel oil.

Materials

Laterite Soil

The laterite soil sample was obtained from a borrow pit in Federal Polytechnic Nekede at a depth of 1.0 to 1.5 meters below the ground surface to avoid topsoil organic matter. The soil was air-dried, pulverized using a rubber mallet, and sieved through a 4.75 mm sieve in accordance with ASTM D421 to obtain a homogeneous sample for testing.

Contaminant (Diesel Oil)

Automotive diesel oil (Automotive Gas Oil - AGO) conforming to EN 590 standards was purchased from a certified fuel station and used as the contaminant. It was introduced into the soil by weight in percentages of 0% (control), 2%, 4%, 6%, and 8% of the dry weight of the soil.

Table 1: Properties of the Diesel Oil Used

Property	Value	Standard Test Method
Specific Gravity @ 15.6°C	0.83	ASTM D1298
Kinematic Viscosity (@ 40°C)	2.6 cSt	ASTM D445
Flash Point	> 65 °C	ASTM D93
Density	850 kg/m³	-

Methods

Sample Preparation and Contamination Procedure

For the contaminated samples, the "dry" contamination method was adopted to ensure uniform distribution (Osuolale & Akinlabi, 2021).

1) The required amount of dry soil for a specific test was weighed.
2) The calculated mass of diesel oil (2%, 4%, 6%, or 8% of the dry soil mass) was measured using a graduated cylinder.
3) The diesel oil was gradually added to the dry soil in a large, clean metal tray and mixed manually with a trowel for 15-20 minutes until a visually homogeneous mixture was achieved, ensuring no visible clumps or oil streaks.
4) The mixture was then sealed in airtight polyethylene bags and cured for 24 hours at room temperature to ensure uniform distribution and interaction of the contaminant with the soil particles before testing [5].

Laboratory Test Procedures: A Step-by-Step Breakdown

Particle Size Distribution (Sieve Analysis) - ASTM D6913

This test was performed only on the natural, uncontaminated soil to establish its baseline classification. A representative dry sample of about 500g (as per your data: 506.00g) was obtained. A stack of sieves was assembled in descending order of aperture size: 4mm, 2.36mm, 1.18mm, 0.6mm, 0.3mm, 0.15mm, 0.075mm, and a pan at the bottom. The sample was placed on the top sieve. The stack was placed on a mechanical sieve shaker and shaken for 10 minutes. The mass of soil retained on each sieve was carefully weighed and recorded. The percentage retained on each sieve, the cumulative percentage retained, and the percentage passing were calculated as shown in your provided data sheet. The coefficients of uniformity (Cu) and curvature (Cc) were determined from the particle size distribution curve.

Atterberg Limits Tests - ASTM D4318

This test was performed on the natural soil and all contaminated samples.

Liquid Limit (LL) using the Casagrande Cup Method:

Approximately 200g of soil (prepared at natural moisture content or contaminated) was mixed with distilled water to form a uniform paste. A portion of the paste was placed in the brass cup of the Casagrande device. A grooving tool was used to cut a standard groove through the sample. The cup was dropped by turning the crank at a rate of 2 revolutions per second. The number of blows required to close the groove along the bottom for a distance of 13mm was recorded. The procedure was repeated at least four times for the same sample at different moisture contents to obtain blow counts between 10 and 40. A flow curve was plotted (Moisture Content vs. Log of Blows). The moisture content corresponding to 25 blows was defined as the Liquid Limit.

Plastic Limit (PL):

A smaller ball of soil was taken from the mixed sample. The ball was rolled on a glass plate with the palm of the hand to form a uniform thread of approximately 3mm diameter.

The rolling continued until the thread crumbled. The moisture content at which the soil crumbled upon reaching a 3mm diameter was recorded as the Plastic Limit. The test was performed three times, and the average moisture content was taken as the PL. The Plasticity Index (PI) was calculated as PI = LL - PL.

Standard Proctor Compaction Test - ASTM D698

The standard Proctor mold (volume 944 cm^3, 4-inch diameter), collar, and rammer (2.5 kg mass, 305 mm drop) were cleaned and weighed. Approximately 5kg of soil was prepared for each compaction point. For contaminated soils, the samples were prepared as described in Section 3.3. For the natural soil, water was added incrementally. The mold was filled with soil in three equal layers. Each layer was subjected to 25 blows from the rammer. After compaction, the collar was removed, the soil was trimmed flush with the mold, and the mold with soil was weighed. A small sample was taken from the center to determine the moisture content. The entire process was repeated for at least 5 different moisture contents. The bulk density and dry density for each point were calculated. A graph of Dry Density vs. Moisture Content was plotted. The peak of the curve gave the Maximum Dry Density (MDD), and the corresponding moisture content was the Optimum Moisture Content (OMC).

California Bearing Ratio (CBR) Test - ASTM D1883

Soil samples for CBR were compacted in the CBR mold (152mm diameter) in five layers, with each layer receiving 56 blows from the standard Proctor rammer (2.5 kg, 305 mm drop). The samples were compacted at their respective OMC and MDD as determined from the Standard Proctor test for each contamination level. A

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surcharge weight was placed on the sample surface to simulate overburden pressure. The entire mold assembly was then immersed in a water tank for 96 hours (4 days) for soaking to simulate the worst-case field condition. After soaking, the mold was removed from the tank and placed under the penetration piston of the CBR testing machine. The piston was seated with a surcharge weight on the sample. The load was applied at a constant strain rate of 1.27 mm/min. The load was recorded at penetrations of 0.64, 1.27, 1.91, 2.54, 3.81, 5.08, 7.62, and so on, up to 12.7mm. The load at 2.54mm and 5.08mm penetration was noted. The CBR value is calculated as the ratio of the load sustained by the soil to the load sustained by a standard crushed rock material, expressed as a percentage. The higher of the two values is reported as the CBR value.

Data Analysis

The data obtained were analyzed quantitatively. Graphs and charts (e.g., compaction curves, CBR vs. diesel content) were plotted using Microsoft Excel. The results for contaminated samples were systematically compared with the natural soil baseline. Trends were identified, and the findings were interpreted and discussed in the context of the mechanisms of contamination and the existing body of literature reviewed in Chapter Two.

RESULTS AND DISCUSSION

A. Index Properties and Classification of Natural Laterite Soil

The results of the sieve analysis and Atterberg limits tests for the natural soil are summarized in Table 2.

Table 2: Geotechnical Properties of Natural Laterite Soil

Property	Value
Particle Size Distribution	
Gravel (>4.75 mm)	4.79 %
Sand (4.75 mm - 0.075 mm)	95.19 %
Fines (<0.075 mm)	0.02 %
Coefficients	
D10	0.0012 mm
D30	0.027 mm
D60	0.40 mm
Cu	333.33
Cc	1.519
Atterberg Limits	
Liquid Limit (LL)	21.3 %
Plastic Limit (PL)	13.1 %
Plasticity Index (PI)	9.4%
AASHTO Classification	**A-2-4**
Compaction (Standard Proctor)	
Maximum Dry Density (MDD)	1.99Mg/cm³
Optimum Moisture Content (OMC)	7.0 %
Strength	
California Bearing Ratio (CBR)	49.30 %

Based on the particle size distribution (Figure 1) and the coefficients of uniformity (Cu = 333.33) and curvature (Cc = 1.519), the soil is well-graded. The AASHTO classification of A-2-4 indicates a granular material with sub-angular particles and slight plastic fines, typically considered a good to excellent subgrade material [14].

Effect of Diesel Oil Contamination on Index Properties

The effect of diesel oil on the Atterberg limits is presented in Table 2 and Figures 2 and 3.

Table 2: Index Properties of Laterite Soil

Diesel Content (%)	Liquid Limit, LL (%)	Plastic Limit, PL (%)	Plasticity Index, PI (%)
0	21.3	13.1	9.4

Effect of Diesel Oil Contamination on Compaction Characteristics

The results of the Standard Proctor tests are summarized in Table 3 and Figures 4 and 5.

Table 3: Compaction Parameters of Laterite Soil at Varying Diesel Content

Diesel Content (%)	Maximum Dry Density (MDD) (Mg/cm^3)	Optimum Moisture Content (OMC) (%)
0	1.99	7.0
3	1.95	9.0
6	1.89	9.9
9	1.86	12.4
12	1.76	15.0

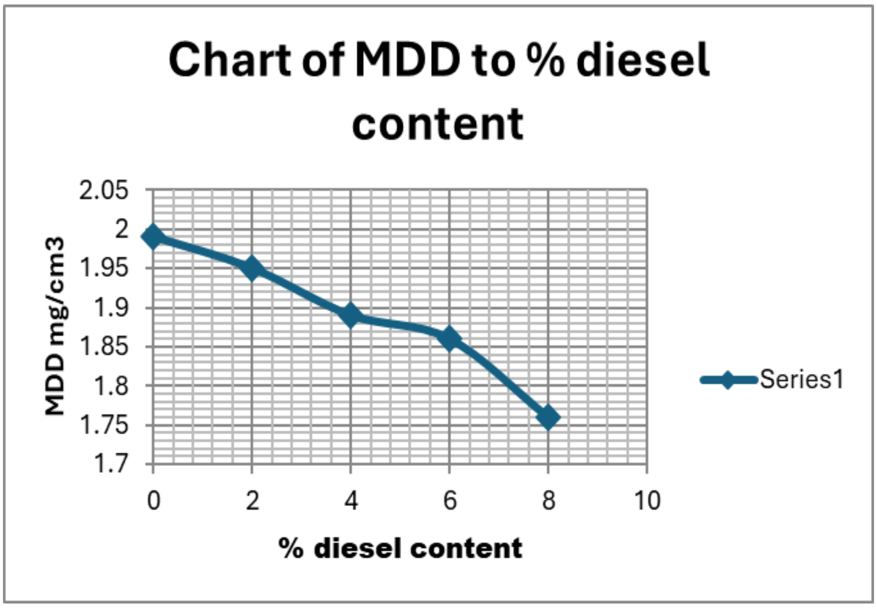

Figure 1: Chart of MDD to % diesel content

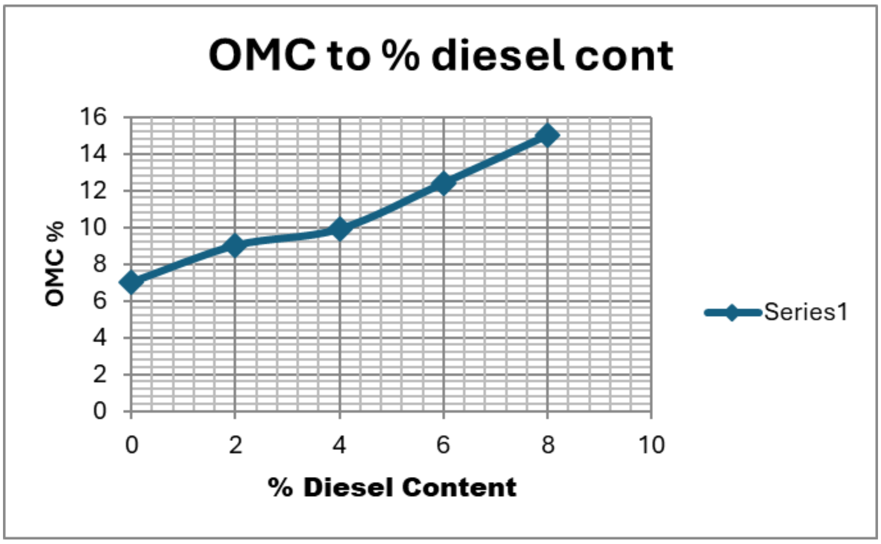

Figure 2: OMC to % diesel content

Discussion: The compaction curves (Figure 1) shift downwards and to the left with increasing diesel content. This signifies a consistent decrease in Maximum Dry Density (MDD) and a decrease in Optimum Moisture Content (OMC), aligning with the work of [15] and [16] The reduction in MDD occurs primarily because diesel oil, which has a lower specific gravity (approx. 0.83) than water, replaces the denser pore water and coats the soil grains. This coating inhibits proper particle rearrangement and lubrication that water typically provides during compaction, leading to a flocculated, less dense structure [17]. The decrease in OMC is a direct consequence of the non-polar nature of diesel; it reduces the soil's water-holding capacity and the need for water to lubricate the particles, meaning less water is required to achieve the "optimum" state for compaction.

Effect of Diesel Oil Contamination on Strength Characteristics (CBR)

The CBR values, which are critical for pavement design, are presented in Table 4 and Figure 6.

Table 4: CBR Values of Laterite Soil at Varying Diesel Content

Diesel Content (%)	CBR Value (%)
0	49.36
3	35.02
6	32.97
9	21.23
12	25.00

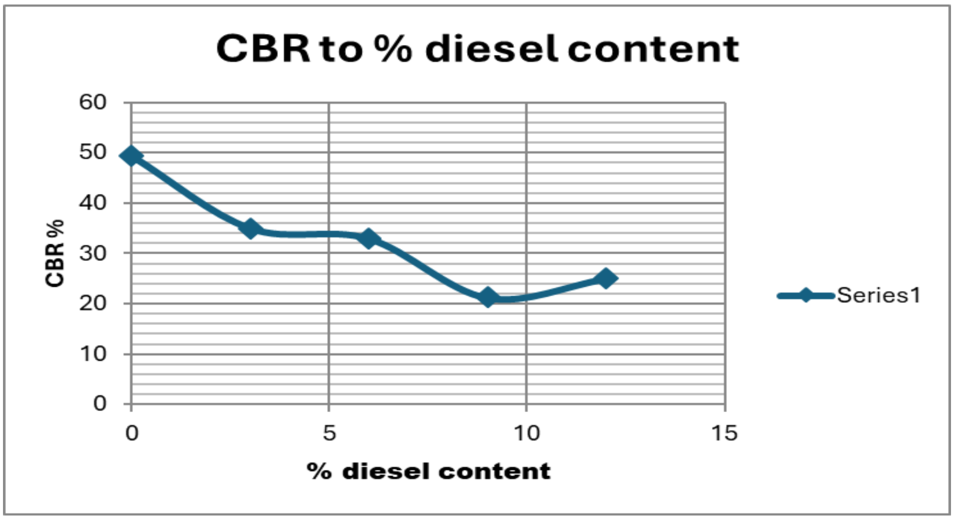

Figure 3: CBR to % Diesel content

Overall Discussion on the Impact of Contamination

The comprehensive test results conclusively demonstrate that diesel oil contamination has a profound and detrimental effect on the geotechnical properties of laterite soil. The soil becomes less plastic, less dense when compacted, and significantly weaker. The change in AASHTO classification reflects a fundamental shift in its engineering character from a desirable material to a less suitable one. These alterations are primarily due to the hydrophobic nature of diesel, which fundamentally changes the soil's interaction with water—the primary agent controlling its geotechnical behavior [18]. The use of such contaminated soil without remediation would lead to poor performance in embankments and pavement subgrades, potentially causing excessive settlement, rutting, and catastrophic failure. This underscores the critical importance of rigorous site investigation and material testing in areas susceptible to hydrocarbon pollution.

Results show progressive reduction in maximum dry density and California Bearing Ratio with increasing diesel content. The deterioration is attributed to lubrication of soil particles, reduced inter-particle friction, and disruption of soil-water interaction.

CONCLUSIONS

1) Based on the results and analysis of this study, it is conclusively stated that:
2) Diesel oil contamination adversely and significantly alters the index, compaction, and strength properties of laterite soil.
3) The strength of the soil, as conclusively indicated by the CBR test, is highly susceptible to degradation, with a severe loss of bearing capacity even at low levels (e.g., 6%) of diesel contamination.
4) The changes in compaction characteristics and index properties indicate that the contaminated soil would be difficult to compact to required densities in the field and would behave in a more granular, less cohesive manner under load compared to uncontaminated soil.

5) Consequently, the use of diesel-contaminated laterite soil as a construction material, particularly in load-bearing applications like pavement subgrades and embankments, is not recommended without prior improvement or stabilization.

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