Evaluating the Compaction Behavior of Oil-Contaminated Soils for Civil Engineering Applications

Abstract

This study investigates the impact of oil contamination on the compaction characteristics of soil, specifically lateritic soil samples from Bori Local Government Area in Rivers State, Nigeria. The research focuses on understanding how varying degrees of oil pollution affect soil's compaction behavior, crucial for civil engineering applications. Compaction tests, including the standard Proctor test, were conducted on both uncontaminated and oil-contaminated soil samples. The results indicate that up to 2% oil addition improves compaction, reducing the optimum moisture content and increasing the maximum dry density. Beyond 4% oil content, no significant enhancement in compaction was observed, and higher oil percentages led to saturation and expulsion of oil, negatively affecting soil strength and bearing capacity. These findings are essential for engineering projects in oil spill regions, providing insights into effective soil compaction strategies and the potential use of oil-contaminated soils in construction.

Comment [a1]: No data is presented on related to strength and bearing capacity in the paper. So, suggested to delete this part.

Keywords: Oil contamination, soil compaction, lateritic soil, Proctor test, maximum dry density, optimum moisture content, civil engineering, soil improvement.

Introduction

Background Information

Soil has been integral to human civilization, serving as agricultural soil and a construction material for building dams, houses, and other structures. The advent of crude oil has expanded its applications, making petroleum oil a global interest [1]. Historical records indicate that various operations, including petroleum oil handling, have been associated with oil spills, which alter the physical and chemical characteristics of soils. These changes affect the engineering properties and compaction characteristics of the soils [2].

Every civil engineering structure, whether buildings, dams, or bridges, relies on the earth's surface or subsurface, making it crucial to understand soil properties under varying conditions. This knowledge helps in controlling and predicting soil properties [1].

Despite frequent oil spills, normal activities must continue. The Niger Delta region of Nigeria faces increasing oil contamination due to oil pollution, impacting the soil's compaction characteristics[3]. Soil compaction, a soil improvement method, involves densifying the soil mass to expel air and excess moisture, thereby reducing voids [4]. This process aims to minimize future soil settlement and the structures it supports [2].

Understanding how different soils respond to compaction and the influence of varying oil contamination levels on soil compaction behavior is essential [5]. Additionally, the economic implications for civil engineering projects must be considered.

Statement of the Problem

Crude oil has been pivotal to the Nigerian economy. However, oil spills and pollution have been recurring problems since the late 1990s, particularly in the Niger Delta region [6]. Concurrently, soil compaction behavior is crucial in civil engineering activities involving earth movement [7]. Therefore, this research seeks to address the following questions:

- How does oil pollution affect the soil's compaction properties?
- Does the degree of oil contamination affect the soil's compaction behavior?
- Does oil influence compaction more effectively than water?

Objectives of Study

This research aims to:

1. Examine any significant variation in the compaction characteristics of oil-contaminated soil.
2. Determine the relationship between oil spill volume and the compaction characteristics of cohesive soil.

Scope of Study

This study will focus on a lateritic soil sample from BORILGA, Rivers State, suitable for road construction and other civil engineering works. It will investigate the relationship between water and oil during compaction operations. This will be achieved by conducting compaction tests on oil-contaminated soil specimens, using the standard Proctor test on uncontaminated soil as the control.

Significance Of The Study

This study will benefit the engineering community, particularly those involved in earth-moving operations. It will highlight any beneficial uses of oil in construction. The findings will assist engineers in deciding when and how much oil to introduce for effective compaction, improving the quality of the finished product. Additionally, this study will pave the way for further research on the impact of oil spill contamination on other soil uses and aid civil engineers in designing and constructing projects in oil spill regions.

Literature Review

Definition of Soil

Soil, to an engineer, refers to any naturally occurring loose or soft deposit resulting from the weathering of rock formations or the decay of organic materials [8]. This includes materials like gravels, sands, calcareous deposits (shell and coral sands), pyroclastics (uncemented volcanic dust), and residual soils like laterites.

Aysen [5] defines soil as the unconsolidated layer covering the earth's surface, consisting of particles of varying sizes and shapes, forming a structure that deforms under natural or artificial forces.

Arora [4] describes soil as the unconsolidated material composed of solid particles produced by the disintegration of rocks. He emphasizes that rocks are the parent material of soil, and partially disintegrated rocks present a challenge in distinguishing between rock and soil.

BS 6110:221 [9] defines soils as the mineral material resulting from rock weathering, while rocks are the relatively hard, naturally occurring parts of the earth's crust that have not broken down into loose, easily excavated material.

Comment [a2]: Delete this section as it is too basic and outside the scope of the paper

Classification of Soil

Soil classification for engineering purposes describes the various soil types found in nature [5]. According to Lambe and Whitman [10], soil classification groups soils with similar behaviors, developed through extensive empirical experience.

Arora [4] outlines the criteria for a useful soil classification:

1. Limited number of groups.
2. Based on relevant engineering properties.
3. Simple and easy to understand terms.

Broad classifications of soil include:

- Particle soil classification
- Textural classification
- AASHTO classification system
- Unified Soil Classification (USC) system
- Indian Standard Classification system (similar to the USC system)

Most soil classification systems in soil mechanics use particle size characteristics, liquid limit, and plasticity index [5]. According to Arora [4], particle size classifications are as follows:

1. Clay: particle size ≤ 0.002 mm
2. Silt: particle size 0.002 – 0.06 mm
3. Sand: particle size 0.06 – 2.0 mm
4. Gravel: particle size ≥ 2.0 mm

The USC system, first developed by Casagrande in 1948 and later modified in 1952, is widely used for engineering problems involving soil [11]. This system uses both particle size and plasticity characteristics and has been standardized by ASTM [4].

Selected Properties of Soil

1. **Void Ratio** Lambe and Whitman [10] define the void ratio as the volume of voids (Vv) to the volume of solids (Vs), expressed as:

   e=VvVsEquation 2.1e = \frac{V_v}{V_s} \quad \text{Equation 2.1}e=VsVv Equation 2.1

   This ratio is typically given as a decimal value and can exceed unity.

2. **Porosity**Porosity is the ratio of the volume of voids (Vv) to the total volume of the soil (V), expressed as:

   n=VvVEquation 2.2n = \frac{V_v}{V} \quad \text{Equation 2.2}n=VVv Equation 2.2

   Both porosity and void ratio measure the soil's denseness. As soil density increases, these values decrease, indicating that higher void ratios accommodate more fluids (water, air, oil)[12].

3. **Density**
   - **Bulk Density** Bulk density is the total mass (M) per unit total volume (V) of soil, expressed as:

     e=MVEquation 2.3e = \frac{M}{V} \quad \text{Equation 2.3}e=VM Equation 2.3

     Also known as wet density, it is expressed in kg/m³, g/m³, or Mg/m³ [13].

4. **Specific Gravity** Specific gravity is the ratio of the mass of a given volume of solids (Ps) to the mass of an equal volume of water (Pw) at 4°C:

   G=PsPwEquation 2.4G = \frac{P_s}{P_w} \quad \text{Equation 2.4}G=PwPs Equation 2.4 [13]

   Most soils have a specific gravity between 2.65 and 2.80. This value is an average for all soil particles. Typical specific gravity values for different soils are:

   Table 1. Specific gravity values for different soils

Soil Type	**Specific Gravity**
Gravel	2.65-2.68
Sand	2.65-2.68
Silty Sand	2.66-2.70
Silt	2.66-2.70
Inorganic Clay	2.68-2.80
Organic Soil	Variable, may fall below 2.0

5. **Moisture Content** All soil contains some moisture. Moisture content, or water content, is the ratio of the mass of water (Mw) to the mass of solids (Ms) in the soil:

   w=MwMsEquation 2.5w = \frac{M_w}{M_s} \quad \text{Equation 2.5}w=Ms MwEquation 2.5 [14]

   Moisture content controls soil behavior and is measured using methods like oven drying, sand bath, and calcium carbide, with the oven-drying method being the standard for accuracy [14].

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Compaction Characteristics of Soil

The Proctor test determines soil compaction characteristics by identifying the optimal amount of water for field compaction and the resulting soil density. According to Lambe [15], laboratory tests should simulate field compaction conditions.

Arora [4] defines compaction as the process of soil densification by reducing air voids. Maximum dry density is achieved at the optimum moisture content, increasing soil mass-density, shear strength, stability, and bearing capacity while reducing compressibility and permeability [16]. The compaction behavior varies between cohesive and cohesionless soils.The compaction behaviour of soil differs for both cohesive and cohesionless soil. For cohesionless soil, the graph according to Arora [4] is as shown below.

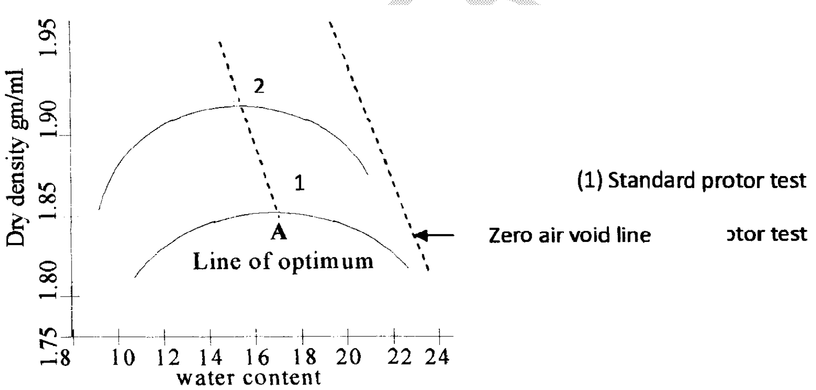


Fig 1. Compaction curve

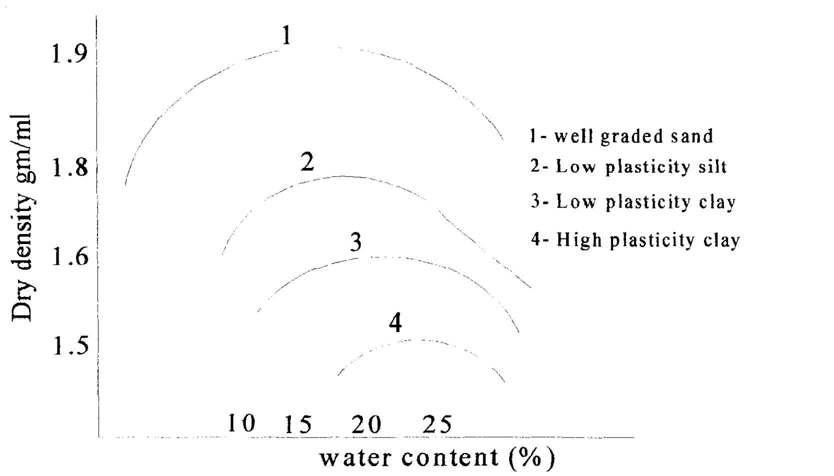
Arora [4] analyzed that for purely sandy soil, the effect of water content on dry density is not well-defined when the moisture content is below the optimum value. The compaction curve shows a large scattering of points in this range, with dry density decreasing as moisture content increases [17]. This phenomenon, termed "bulking of sand," is due to capillary tension in the pore water, with maximum bulking occurring at about 4-5% moisture content [18].

Coarse-grained, cohesionless soils do not absorb water and lack lubrication, thus they do not exhibit a distinct optimum moisture content (OMC) [4].

Among the factors affecting compaction—moisture content, amount of compaction, type of soil, method of compaction, and admixtures—this study focuses on the effects of soil type and admixtures.

Compaction Curve for Different Soils

The graph below shows the effect of soil type on the dry density achieved.



Compaction curve for different soils **Fig2**

On the presence of admixtures, such as bitumen, enhances the compaction characteristics of soil. Bitumen, a hydrocarbon soluble in carbon disulfide obtained from the destructive distillation of organic minerals like coal, is a commonly used admixture [19].

Bitumen's effectiveness depends on the type and amount used. When mixed with inorganic soils, bitumen aids in bituminous stabilization. In cohesionless soils, bitumen bonds the particles as cementing agents. In cohesive soils, bitumen plugs voids and provides waterproofing, helping maintain low moisture content and increasing bearing capacity [20]. Typically, the bitumen used ranges from 4 to 7% by weight.

Comment [a4]: Delete this section as the content is too basic and outside the scope of the paper

Contamination in Soil

Oil (crude oil) is a significant soil contaminant, as shown by Beckett [6]. Various sources of soil contaminants include:

- **Heavy Metals:** Cadmium, Lead, Zinc, Copper, Nickel
- **Inorganic:** Sulfate, Asbestos
- **Organic:** Oil, Tars, Chlorinates, Hydrocarbons, PCBs, Dioxins

- **Gases:** Landfill Gas

Pollution vs. Contamination

Beckett [6] defines contamination as the introduction or presence of foreign substances in the environment that may cause damage. Contamination alone does not suffice for pollution. Pollution, according to Baljet[9], is an undesirable change in the physical, chemical, or biological characteristics of air, land, and water, harmful to living beings. The Royal Commission on Environmental Pollution defines it as substances introduced by humans that pose hazards to health, harm resources, damage structures, or interfere with legitimate uses of the environment [15].

Crude Oil

Crude oil is a naturally occurring mixture of hydrocarbons and sulfur, nitrogen, and oxygen derivatives, extracted in liquid form [16]. It is classified based on quality into:

1. Paraffin base
2. Asphaltic base
3. Intermediate base
4. Hybrid (naphthenic) base

Paraffin base crude oils yield residues with paraffin wax, while asphaltic base crude oils yield asphaltic materials [18]. Intermediate base crude oils produce residues with both paraffin wax and asphaltic materials, and naphthenic base crude oils contain mainly asphaltic materials with some paraffin wax[14].

Soil-Oil Interaction

Oil spillage has environmental and socio-economic impacts in petroleum-producing areas, such as Nigeria's riverine regions [17]. Hjeldnes et al. [19] found that oil spreads similarly in soil and along container walls, with movement slowing after seven days. The shape of the contaminated zone depends on the sand's water content.

Meegoda and Ratnaweera[3] studied oil-contaminated soils, finding that adding 3% motor oil affects soil classification. Treatments like heating, solvents, and surfactants were tested, with surfactants producing near-virgin soil. Low-temperature thermal treatment was ineffective for all soils.

Properties of Oil-Contaminated Soil

Al-Sanad et al. [1] investigated basic soil properties, California Bearing Ratio (CBR), direct shear, and triaxial tests on oil-contaminated soil. They found that up to 4% oil contamination improved compaction and CBR values, but beyond 6%, dry density decreased. Srivastava and Pandey [17] observed that oil addition decreases Optimum Moisture Content (OMC) and initially increases Maximum Dry Density (MDD) before it falls, with 6% oil yielding the highest MDD. They attributed this to oil's lubricating effect, reducing water needed for maximum density. However, strength parameters, like cohesion and internal friction angle, decrease with oil content over 3% [17].

Key findings include:

1. Specific gravity of both alluvial soil and sand decreases.
2. Liquid limit and plasticity index of alluvial soil increase, indicating potential settlement issues.
3. Oil improves compaction behavior by reducing OMC, with a small effect on MDD.
4. Compression index of alluvial soil increases, suggesting higher settlement potential.
5. Strength parameters reduce with oil addition.

Research Methodology

Introduction

This chapter outlines the procedures for conducting this study, covering the following sections:

- Area of Study and Characteristics of the Study Population
- Data Collection
- Method of Data Analysis

Area of Study and Characteristics of the Study Population

The study examines the effect of oil spills (using petrol-diesel) on the compaction characteristics of soils, specifically focusing on laterite soil samples from Bori Local Government Area of Rivers State, Nigeria. This area is selected due to its history of oil spills and its significance as an oil-producing region.

Method of Data Collection

Primary data on the compaction characteristics of petrol-diesel spills were collected through laboratory experiments and observations.

Data Collection Instruments The instruments used are classified based on the type of data required:

- **Soil Identification Instruments:** These include sieve analysis classification tests, Atterberg (consistency) limit tests, and specific gravity tests. These tests were conducted according to BS 1377 Part 4 [8] to understand the properties of the uncontaminated soil.
- **Standard Proctor Test:** This apparatus was used to determine soil moisture content and dry densities of the dry soil, following BS 1377 Part 4.

Data Collection Schedule The laboratory experiment schedule for both air-dried and oil-contaminated soil samples is as follows:

Table 2. Laboratory experiment schedule for both air-dried and oil-contaminated soil samples

Specimen Designation	Specimen Makeup	Test Carried Out
A1	Natural air-dried sample	Consistency limit test
A2	Natural air-dried sample	Sieve analysis
A3	Natural air-dried sample	Specific gravity test
B1	Air-dried sample + varying % water (Proctor test)	Proctor test
B2	Sample + 16% OMC (water) + varying oil	Bulk density determination
C1	Air-dried sample + varying % oil	Bulk density determination
C2	Air-dried sample + 2% petrol-diesel + varying water	Proctor test
C3	Air-dried sample + 4% petrol-diesel + varying water	Proctor test
C4	Air-dried sample + 5% petrol-diesel + varying water	Proctor test
C5	Air-dried sample + 6% petrol-diesel + varying water	Proctor test

"A" denotes identification tests, "B" denotes bulk density tests, and "C" denotes Proctor compaction tests. Oil was added in terms of volume (ml) to reflect standard Proctor test methods before compactive effort was applied. Bulk density was determined by dividing the weight of the compacted soil by the volume of the mold. This procedure was repeated for varying percentages of petrol-diesel oil.

Presentation and Analysis of Data

Data were presented using graphs and charts, including:

- **Optimum Moisture Content Curve:** Dry densities were plotted against the percentage water content, with the highest dry density indicating the optimum moisture content. This was done for both uncontaminated and oil-contaminated soils.
- **Optimum Oil Content Graph:** Bulk densities of oil-contaminated soil were plotted against the percentage of oil content, providing a basis for comparison with the optimum moisture content curve.
- **Sieve Analysis Curve:** For the uncontaminated soil, percentages passing each sieve were plotted against sieve sizes to describe the soil type.

Parameters were obtained using basic soil mechanics equations:

$$\text{Dry Density} = \frac{W_s}{V}$$

where W_s is the weight of dry soil, and V is the volume of the soil sample.

$$\text{Percentage Water Content} = \frac{W_w \times 100\%}{W}$$

where WwW_wWw is the weight of water, and WWW is the weight of the soil.

Percentageoilcontent=$\frac{V_{d\,x\,100\%}}{V_S}$............. Equation3.2

Where V_d= volume of petro diesel added to soil

V = Volume of soil

Bulk density = $\frac{W}{V}$

Where W = total weight of the soil sample

V = Total volume of soil sample.

RESULTS AND DISCUSSION

This chapter discusses the results obtained from the data analysis. The results are presented according to the research experiments conducted. Initially, identification test results are presented to describe the type and nature of the soil used for the experiment. Subsequently, various compaction test results are compared and analyzed alongside the standard Proctor test (used as control without any addition of petrol-diesel). Differences, if any, are noted and commented upon.

Identification Tests

The following experiments were carried out as outlined in Table 3 of Chapter Three. Some results are presented below, while other relevant data are placed in the appendix.

Consistency Limit Tests

The Atterberg limit test results are presented below:

Table 3: Consistency Limit Results

Consistency Limit	**Moisture content values (%)**
Liquid Limit	28.0
Plastic Limit	18.8

These values fall within the range (15-32% moisture) obtained by both Arora[4] and Obi-Egbedi[13].

Sieve Analysis

The graph of the sieve analysis of the air-dried sample is presented in Appendix A. Laterite, which contains a good combination of fine clay particles and sand particles, conforms to the distribution shown above. This chart indicates a well-graded sample since Cu > 2 [4]. A well-graded soil typically has a Cu value greater than 2, confirming the sample selected for the experiment is not a gap-graded sample but a well-graded one[6]. From the distribution curve:

- D10 = 0.35
- D30 = 0.8
- D60 = 1.70

The coefficients are calculated as follows:

- Cu (Coefficient of uniformity) = D60 / D10 = 1.70 / 0.35 = 4.86
- Cc (Coefficient of curvature) = (D30^2) / (D10 * D60) = 1.1

Comment [a5]: Figure not found in Appendix A. Add the figure and it should be called as "grain size distribution curve" and not "graph of sieve analysis"

Comment [a6]: Use Unified soil classification, which is standard. Mention % Fines and % Sand in the soil. If % Fines<5, As per this system, the soil is Poorly graded as Cu<6 and not Well graded

The value of Cc = 1.1 confirms the soil is well-graded, meeting the requirements for most engineering compaction purposes, resulting in better compaction ease.

Specific Gravity Test

The specific gravity of the uncontaminated sample was approximately 2.475, similar to results obtained by Srivastava and Pandey [17]. Obi-Egbedi[13] also reported specific gravity values ranging from 2.50 to 2.53 for laterite sourced from Port Harcourt.

Compaction Test

Several compaction tests were conducted to gather the desired results. The standard Proctor compaction test was first carried out, followed by compaction tests on specimens contaminated with varying degrees of oil. Additionally, a compaction test using only oil (petrol-diesel) without any added water was conducted.

Normal Compaction Test (Proctor Test)

The state of soil compaction is measured using the dry density, related to moisture content. As water is added to dry soil, absorbed water films form around the particles, lubricating them and increasing density. Beyond a certain point, absorbed films push particles apart, reducing density. The maximum dry density occurs at the optimum moisture content.

For the natural air-dried sample, the results were:

- Maximum dry density = 1.80 mg/m^3
- Optimum moisture content = 16%

These values align with the range of 8-20% moisture content for soils varying from sandy silt to clay soil [4] and similar research by Srivastava and Pandey on alluvial soil [17].

Soil Sample and Percentage Oil Addition

The compaction test results on specimens with specific percentages of oil addition are shown below.

Compaction Tests Using Only Oil

The bulk density of the air-dried sample at varying oil content percentages is plotted in Chart 1. Below 4%, oil addition positively impacts compaction without added water. The effective oil content recorded (2%) is within the range obtained before the transition in effect, as shown in Chart 1.

A transition in effect occurs between 4% to 6% oil content, where negligible changes in bulk density are observed. Beyond 6%, oil does not reduce maximum dry density due to intermolecular forces between the soil-oil-water matrix. At oil content above 14%, the soil saturates with oil, forcing excess oil out upon compaction.

Comparative Analysis of Compaction Curve

The common shapes of compaction curves fall within the types described by Lee and Suedkamp [11]. The optimum values of compaction results are presented in Table 4 below:

Table 4: Optimum Values of Compaction Results

Specimen	Ptmas Mg/m³	OMC (%)
Natural air dried	1.80	16.00
Air dried + 2% oil	1.85	13.00
Air dried + 4% oil	1.79	15.6
Air dried + 5% oil	1.80	14.00
Air dried + 6% oil	1.80	15.20

Comment [a7]: Use Standard symbols

The graphical representation shows a significant reduction in moisture content to achieve maximum dry density during compaction, attributed to the oil-water interaction and oil's lubricating effect.

From the results, the most effective compaction occurs at 2% oil addition, yielding maximum dry density and minimum moisture content. This "Effective Oil Content" (EOC) produces an increase in maximum dry density with a reduction in optimum water content.

Oil Addition Effect on Compaction

Except for the EOC, other oil additions have no positive effect on the maximum dry density, remaining constant at ±0.01 Mg/m³. Observations indicate that at least 4% oil content results in saturation and expulsion of diesel oil and some water, reducing moisture content and dry density.

For practical compaction, the process should stop before soil void saturation to achieve the desired density. Above certain oil addition percentages, the oil negatively affects compaction, reducing soil strength and bearing capacity, as concluded by Srivastava and Pandey [17]. They noted that "The strength parameters reduce due to oil addition to soils," impacting bearing capacity and slope stability in construction on contaminated soils [17].

Discussion

This chapter discusses the results obtained from the data analysis. The results are presented according to the research experiments conducted. Initially, identification test results are presented to describe the type and nature of the soil used for the experiment. Subsequently, various compaction test results are compared and analyzed alongside the standard Proctor test (used as control without any addition of petrol-diesel). Differences, if any, are noted and commented upon.

Identification Tests

The following experiments were carried out as outlined in Table 5 of Chapter Three. Some results are presented below, while other relevant data are placed in the appendix.

Consistency Limit Tests

The Atterberg limit test results are presented below:

Table 5: Consistency Limit Results

Consistency Limit	**Moisture content values (%)**
Liquid Limit	28.0
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The coefficients are calculated as follows:

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- Cc (Coefficient of curvature) = $(D_{30}^2) / (D_{10} * D_{60}) = 1.1$

The value of Cc = 1.1 confirms the soil is well-graded, meeting the requirements for most engineering compaction purposes, resulting in better compaction ease.

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Several compaction tests were conducted to gather the desired results. The standard Proctor compaction test was first carried out, followed by compaction tests on specimens contaminated with varying degrees of oil. Additionally, a compaction test using only oil (petrol-diesel) without any added water was conducted.

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A transition in effect occurs between 4% to 6% oil content, where negligible changes in bulk density are observed. Beyond 6%, oil does not reduce maximum dry density due to intermolecular forces between the soil-oil-water matrix [6]. At oil content above 14%, the soil saturates with oil, forcing excess oil out upon compaction.

Comment [a8]: This section is repeated. Delete.

Comparative Analysis of Compaction Curve

Comment [a9]: This section is repeated. Delete

The common shapes of compaction curves fall within the types described by Lee and Suedkamp [11]. The optimum values of compaction results are presented in Table 6below:

Table 6: Optimum Values of Compaction Results

Specimen	Ptmas Mg/m³	OMC (%)
Natural air dried	1.80	16.00
Air dried + 2% oil	1.85	13.00
Air dried + 4% oil	1.79	15.6
Air dried + 5% oil	1.80	14.00
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From the results, the most effective compaction occurs at 2% oil addition, yielding maximum dry density and minimum moisture content. This "Effective Oil Content" (EOC) produces an increase in maximum dry density with a reduction in optimum water content.

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For practical compaction, the process should stop before soil void saturation to achieve the desired density. Above certain oil addition percentages, the oil negatively affects compaction, reducing soil strength and bearing capacity, as concluded by Srivastava and Pandey [17]. They noted that "The strength parameters reduce due to oil addition to soils," impacting bearing capacity and slope stability in construction on contaminated soils.

Research Context

This research investigates the impact of oil spills on the compaction characteristics of soil. The study uses diesel oil and lateritic soil sourced from Bori LGA of Rivers State, located in the southeastern part of Nigeria. The findings are valuable for those utilizing lateritic soil in construction, particularly in road and flexible pavement construction.

The research methodology was inspired by a similar study conducted in Kuwait by Srivastava and Pandey [17] on alluvial and sandy soil. The approach is divided into two phases: Phase one involves soil identification experiments to classify the soil type, and Phase two comprises compaction tests on various soil + oil + water matrices. The compaction of natural air-dried specimens served as the control experiment. The results are presented in charts and tables and analyzed through comparison with the control experiment. Similar trends in soil behavior, specifically a positive increase in compaction up to a certain oil content, were observed, consistent with the findings of Srivastava and Pandey [17]. The compaction characteristics also align with the four general charts described by Lee and Suedkamp [11].

The research demonstrates that adding oil positively influences the compaction behavior of soil, increasing dry density and reducing optimum moisture content (OMC) up to a certain point. Beyond this point, further oil addition is not desirable, although an effective oil content was identified.

Conclusion

From the analysis of the experimental results on the various prepared specimens, the following conclusions can be drawn:

1. Oil addition (diesel) affects the compaction behavior of soil.
2. The most effective compaction is achieved with less than 4% oil addition to the lateritic soil, termed "effective oil content." This results in increased maximum dry density and reduced OMC compared to the control experiment.
3. Below the effective oil content, oil positively contributes to the compaction process.
4. Adding oil beyond the effective oil content does not significantly enhance the compaction process and often leads to a loss of soil shear strength.

Recommendations

Based on the findings, the following recommendations are made:

1. A controlled amount of oil can be added to improve the compaction behavior of laterite.
2. Oil-contaminated soils can be utilized for road construction if the oil content is less than the effective oil content (EOC) of the soil.
3. Compaction of oil-contaminated soil should be performed when the moisture content can be controlled (e.g., during the dry season) to ensure optimal compaction.

Comment [a10]: Revise. Oil is contamination. It is not added in practice.

Recommendations for Further Research

Acknowledging that no single study can comprehensively cover all aspects of a subject, further research is recommended in the following areas:

1. The effect of oil contamination on the shear strength of soil.
2. The impact of different oils on the compaction characteristics and shear strength of soils.

References

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Comment [a11]: Add Year

Comment [a12]: Indicate where this paper is used. Not relevant. Suggested to remove this Reference as chemistry aspects are not discussed in the Results

Comment [a13]: Suggest to remove these references

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COMPACTION TEST DATA APPENDIX A_1

Comment [a14]: Observations are Not to be included in the paper. Compaction curves are not found. Add compaction curves.

A1

Location No:……………………. Name:……………………………….. Sample No:………………… Date: 20th July 2008

WORK/UNIT VOLUME

1. STANDARD COMPACTION USING Proctor mould: volume …. **996**…..cm^3 No of LAYERS…..**3**…… ESTIMATED
2. A. A. S. H. O. COMPACTION USING C. B. R. MOULD: VOLUME…………..cm^3 TOTALBLOWS..**25**/layer

ORIGINAL

3. MODIFIED A. A. S. H. O. Using (1mg/ cm^3) WEIGHT OF Rammer…… **2.5**kg MOISTURE….**6.0**…..%

COMPACTION	**1st trial**	**2nd trial**	**3rd trial**	**4th trial**	**5th trial**		
WEIGHT OF MOULD + WET SOIL: W_2 gm	**6128**	**6320**	**6417**	**6484**	**6493**		
WEIGHT OF MOULD : W_1 gm	**4433**	**4433**	**4433**	**4433**	**4433**		
WEIGHT OF WET SOIL : $W_2 - W1$ gm	**1695**	**1887**	**1984**	**2051**	**2060**		
DENSITY OF WET SOIL Y Mg/m^3	**1.70**	**1.89**	**1.99**	**2.06**	**2.07**		

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COMPACTION	**1st trial**	**2nd trial**	**3rd trial**	**4th trial**	**5th trial**		
WEIGHT OF WET SOIL + CONTAINER: W_W gm	**63.96**	**78.03**	**78.71**	**87.15**	**95.17**		
WEIGHT OF DRY SOIL + CONTAINER : W_d gm	**60.00**	**72.75**	**72.66**	**79.57**	**85.03**		
WEIGHT OF CONTAINER : $W_c$gm	**27.85**	**32.13**	**27.78**	**28.79**	**29.19**		

WEIGHT OF DRY SOIL : W_d – Wcgm	**32.15**	**40.62**	**44.88**	**50.78**	**55.84**		
WEIGHT OF MOISTURE : W_w – W_d gm	**3.96**	**5.28**	**6.05**	**7.58**	**10.14**		
MOISTURE CONTENT %	**12.32**	**13.00**	**13.48**	**14.93**	**18.16**		
DRY DENSITY Y Mg/m^3	**1.51**	**1.51**	**1.75**	**1.79**	**1.75**		

@ ENGINEERING LABORATORY EQUIPMENTS LIMITED **SIGNED:……………………………………**

COMPACTION TEST DATA **APPENDIX A_2**

A2

Location No:……………………. Name:………………………………….. Sample No:………………… Date: 20th July 2008

WORK/UNIT VOLUME

1. STANDARD COMPACTION USING Proctor mould: volume …. **996**…..cm^3 No of LAYERS…..**3**…… ESTIMATED

2. A. A. S. H. O. COMPACTION USING C. B. R. MOULD: VOLUME……………cm^3 TOTALBLOWS..**25**/layer

ORIGINAL

3. MODIFIED A. A. S. H. O. Using (1mg/ cm^3) WEIGHT OF Rammer…… **2.5**kg MOISTURE….**6.0**…..%

COMPACTION	**2% OIL**	**4% OIL**	**6% OIL**	**10% OIL**	**14% OIL**	**18% OIL**	**22% OIL**
WEIGHT OF MOULD + WET SOIL: W_2 gm	**6000**	**6094**	**6098**	**6232**	**6284**	**6334**	**6362**
WEIGHT OF MOULD : W_1 gm	**4433**	**4433**	**4433**	**4433**	**4433**	**4433**	**4433**
WEIGHT OF WET SOIL : W_2 – W1 gm	**1567**	**1661**	**1665**	**1799**	**1851**	**1901**	**1929**
DENSITY OF WET SOIL Y Mg/m^3	**1.57**	**1.67**	**1.67**	**1.75**	**1.86**	**1.91**	**1.94**

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COMPACTION							
WEIGHT OF WET SOIL + CONTAINER: W_W gm							
WEIGHT OF DRY SOIL + CONTAINER : W_d gm							
WEIGHT OF CONTAINER : $W_c$gm							
WEIGHT OF DRY SOIL : $W_{d} - W_c$gm							
WEIGHT OF MOISTURE : $W_w - W_d$ gm							
MOISTURE CONTENT %							
DRY DENSITY Y Mg/m^3							

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COMPACTION TEST DATA **APPENDIX A_2**

A3

Location No:……………………. Name:………………………………….. Sample No:………………… Date: 20th July 2008

WORK/UNIT VOLUME

1. STANDARD COMPACTION USING Proctor mould: volume …. **996**…..cm^3 No of LAYERS…..**3**…… ESTIMATED
2. A. A. S. H. O. COMPACTION USING C. B. R. MOULD: VOLUME……………cm^3 TOTALBLOWS..**25**/layer
   ORIGINAL
3. MODIFIED A. A. S. H. O. Using (1mg/ cm^3) WEIGHT OF Rammer…… **2.5**kg MOISTURE….**6.0**…..%

COMPACTION	1	2	3	4	5	6	7	8
WEIGHT OF MOULD + WET SOIL: W_2 gm	6170	6260	6341	6461	6494	6518	6455	6392
WEIGHT OF MOULD : W_1 gm	4433	4433	4433	4433	4433	4433	4433	4433
WEIGHT OF WET SOIL : $W_2 - W1$ gm	1737	1827	1908	2028	2061	2085	2022	1961
DENSITY OF WET SOIL Y Mg/m^3	1.74	1.83	1.92	2.04	2.07	2.09	2.03	1.97

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COMPACTION	10	19	15	16	21	11	18	13
WEIGHT OF WET SOIL + CONTAINER: W_W gm	99	100	90.5	102	118	105	104	110
WEIGHT OF DRY SOIL + CONTAINER : W_d gm	92	94	85	94.5	106	96	94	98
WEIGHT OF CONTAINER : $W_c$gm	28	30	31	29	27.5	29.5	30.5	27.5
WEIGHT OF DRY SOIL : $W_d - W_c$gm	64	64	54	65.5	78.5	63.5	63.5	70.5
WEIGHT OF MOISTURE : $W_w - W_d$ gm	7.0	6.0	5.5	7.5	12	9	10	12
MOISTURE CONTENT %	10.94	9.38	10.19	11.45	15.29	14.17	15.75	17.02
DRY DENSITY Y Mg/m^3	1.57	1.67	1.74	1.80	1.83	1.83	1.75	1.68

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COMPACTION TEST DATA APPENDIX A_2

A4

Location No:…………………… Name:……………………………….. Sample No:………………… Date: 20th July 2008

WORK/UNIT VOLUME

1. STANDARD COMPACTION USING Proctor mould: volume …. **996**…..cm^3 No of LAYERS…..**3**…… ESTIMATED

2. A. A. S. H. O. COMPACTION USING C. B. R. MOULD: VOLUME……………cm^3 TOTALBLOWS..**25**/layer

ORIGINAL

3. MODIFIED A. A. S. H. O. Using (1mg/ cm^3) WEIGHT OF Rammer…… **2.5**kg MOISTURE….**6.0**…..%

COMPACTION	**1**	**2**	**3**	**4**	**5**	**6**	
WEIGHT OF MOULD + WET SOIL: W_2 gm	**6118**	**6242**	**6406**	**6484**	**6490**	**6468**	
WEIGHT OF MOULD : W_1 gm	**4433**	**4433**	**4433**	**4433**	**4433**	**4433**	
WEIGHT OF WET SOIL : $W_2 - W1$ gm	**1685**	**1809**	**1973**	**2051**	**2057**	**2035**	
DENSITY OF WET SOIL Y Mg/m^3	**1.69**	**1.82**	**1.98**	**2.06**	**2.07**	**2.04**	

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COMPACTION	**18**	**2**	**7**	**9**	**5**	**11**	
WEIGHT OF WET SOIL + CONTAINER: W_W gm	**47**	**60**	**62**	**78**	**72**	**76**	
WEIGHT OF DRY SOIL + CONTAINER : W_d gm	**43**	**56**	**57**	**68**	**65**	**69**	
WEIGHT OF CONTAINER : $W_c$gm	**3**	**20**	**20**	**20**	**20**	**20**	
WEIGHT OF DRY SOIL : $W_d -$ Wcgm	**40**	**36**	**37**	**48**	**45**	**49**	
WEIGHT OF MOISTURE : $W_w - W_d$	**4**	**4**	**5**	**10**	**7**	**7**	

gm							
MOISTURE CONTENT %	**10.0**	**11.1**	**13.5**	**20.8**	**15.6**	**14.2**	
DRY DENSITY Y Mg/m^3	**1.54**	**1.64**	**1.75**	**1.71**	**1.79**	**1.78**	

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COMPACTION TEST DATA **APPENDIX A_2**

A5

Location No:……………………. Name:………………………………….. Sample No:………………… Date: 20th July 2008

WORK/UNIT VOLUME

1. STANDARD COMPACTION USING Proctor mould: volume …. **996**…..cm^3 No of LAYERS…..**3**…… ESTIMATED
2. A. A. S. H. O. COMPACTION USING C. B. R. MOULD: VOLUME……………cm^3 TOTALBLOWS..**25**/layer

ORIGINAL

3. MODIFIED A. A. S. H. O. Using (1mg/ cm^3) WEIGHT OF Rammer…… **2.5**kg MOISTURE….**6.0**…..%

COMPACTION	**1**	**2**	**3**	**4**	**5**		
WEIGHT OF MOULD + WET SOIL: W_2 gm	**6146**	**6238**	**6376**	**6492**	**6469**		
WEIGHT OF MOULD : W_1 gm	**4433**	**4433**	**4433**	**4433**	**4433**		
WEIGHT OF WET SOIL : $W_2 - W1$ gm	**1713**	**1805**	**1943**	**2059**	**2036**		
DENSITY OF WET SOIL Y Mg/m^3	**1.720**	**1.812**	**1.951**	**2.067**	**2.044**		

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COMPACTION	**6**	**7**	**5**	**3**	**4**		
WEIGHT OF WET SOIL + CONTAINER: W_W	**79**	**67**	**52**	**62**	**68**		

gm							
WEIGHT OF DRY SOIL + CONTAINER : W_d gm	**73.5**	**63**	**49**	**56**	**61**		
WEIGHT OF CONTAINER : $W_c$gm	**22**	**21**	**22**	**20**	**19**		
WEIGHT OF DRY SOIL : W_{d-} Wcgm	**51.5**	**42**	**27**	**36**	**42**		
WEIGHT OF MOISTURE : W_{w-} W_d gm	**5.5**	**4**	**3**	**6**	**7**		
MOISTURE CONTENT %	**10.680**	**9.524**	**11.111**	**16.667**	**16.660**		
DRY DENSITY Y Mg/m^3	**1.554**	**1.654**	**1.756**	**1.772**	**1.753**		

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COMPACTION TEST DATA **APPENDIX A_2**

A6

Location No:……………………. Name:………………………………….. Sample No:………………… Date: 20th July 2008

WORK/UNIT VOLUME

1. STANDARD COMPACTION USING Proctor mould: volume …. **996**…..cm^3 No of LAYERS…..**3**…… ESTIMATED
2. A. A. S. H. O. COMPACTION USING C. B. R. MOULD: VOLUME……………cm^3 TOTALBLOWS..**25**/layer

ORIGINAL

3. MODIFIED A. A. S. H. O. Using (1mg/ cm^3) WEIGHT OF Rammer…… **2.5**kg MOISTURE….**6.0**…..%

COMPACTION	**1**	**2**	**3**	**4**	**5**		
WEIGHT OF MOULD + WET SOIL: W_2 gm	**6126**	**6278**	**6413**	**6491**	**6480**		

WEIGHT OF MOULD : W_1 gm	**4433**	**4433**	**4433**	**4433**	**4433**		
WEIGHT OF WET SOIL : $W_{2-}W1$ gm	**1693**	**1845**	**1980**	**2058**	**2047**		
DENSITY OF WET SOIL Y Mg/m^3	**1.70**	**1.85**	**1.99**	**2.07**	**2.06**		

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COMPACTION	**1**	**2**	**10**	**8**	**9**		
WEIGHT OF WET SOIL + CONTAINER: W_W gm	**74**	**56**	**62**	**58**	**62**		
WEIGHT OF DRY SOIL + CONTAINER : W_d gm	**69.0**	**53.0**	**57.0**	**53.0**	**56.5**		
WEIGHT OF CONTAINER : $W_c$gm	**20**	**20**	**20**	**20**	**20**		
WEIGHT OF DRY SOIL : W_{d-} Wcgm	**49.0**	**33.0**	**37.0**	**33.0**	**36.5**		
WEIGHT OF MOISTURE : $W_{w-}W_d$ gm	**5.0**	**3.0**	**5.0**	**5.0**	**5.5**		
MOISTURE CONTENT %	**10.204**	**9.091**	**13.514**	**15.152**	**15.06**		
DRY DENSITY Y Mg/m^3	**1.54**	**1.70**	**1.75**	**1.77**	**1.79**		

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COMPACTION TEST DATA **APPENDIX A_2**

A7

Location No:……………………. Name:………………………………….. Sample No:…………………. Date: 20th July 2008

WORK/UNIT VOLUME

1. STANDARD COMPACTION USING Proctor mould: volume …. **996**…..cm^3 No of LAYERS…..**3**…… ESTIMATED

2. A. A. S. H. O. COMPACTION USING C. B. R. MOULD: VOLUME……………cm^3 TOTALBLOWS..**25**/layer

ORIGINAL

3. MODIFIED A. A. S. H. O. Using ($1mg/ cm^3$) WEIGHT OF Rammer…… **2.5**kg MOISTURE….**6.0**…..%

COMPACTION	**0% OIL**	**2% OIL**	**4% OIL**	**6% OIL**			
WEIGHT OF MOULD + WET SOIL: W_2 gm	**6500**	**6481**	**6471**	**6468**			
WEIGHT OF MOULD : W_1 gm	**4433**	**4433**	**4433**	**4433**			
WEIGHT OF WET SOIL : $W_2 - W1$ gm		**2054**	**2054**	**2035**			
DENSITY OF WET SOIL Y Mg/m^3	**2.075**	**2.062**	**2.062**	**2.043**			

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COMPACTION							
WEIGHT OF WET SOIL + CONTAINER: W_W gm							
WEIGHT OF DRY SOIL + CONTAINER : W_d gm							
WEIGHT OF CONTAINER : $W_c$gm							
WEIGHT OF DRY SOIL : $W_d -$ Wcgm							
WEIGHT OF MOISTURE : $W_w - W_d$ gm							
MOISTURE CONTENT %							
DRY DENSITY Y							

Mg/m^3							

APPENDIX C_2

Range of Optimum Water Content

Sand	Sandy silt or silty sand	Silt	Clay
6 to 10%	8 TO 12%	12 TO 16%	14 TO 20%

Source: Soil mechanics and foundation engineering Arora, K. R. (2005)

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APPENDIX B_2

SOIL TESTING LABORATORY

LIQUID LIMIT DETERMINATION

Sample No:…………………………………………………… Project No:………………………………………

Boring No:……………………………………………………… Location:…………………………………………

Depth of Sample:…………………………………………..

Description of Sample:………………………………………………………………

Testes by :………………………………………………………………………………

Date:…………………………………………………

Determination No.	**1**	**2**	**3**
Number of drops	**30**	**27**	**25**
Can No.	**A3/B15**	**09/H2**	**40/70**
Weight of can + moist soil, W_1 (g)	**47.60**	**44.80**	**46.10**
Weight of can +dry soil, W_2 (g)	**42.70**	**41.00**	**41.70**
Weight of can W_C (g)	**28.00**	**29.70**	**27.80**
Weight of water, W_w (g)	**4.90**	**3.90**	**4.40**
Weight of dry soil, W_s (g)	**14.70**	**11.30**	**13.90**
Moisture content, W (%)	**18.59**	**15.51**	**31.65**

From the flow curve, the liquid limit is **28%**

APPENDIX B_2

SOIL TESTING LABORATORY

PLASTIC LIMIT DETERMINATION AND PLASTICITY INDEX

Sample No:……………………………………………………… Project No:……………………………………

Boring No:…………………………………………………… Location:………………………………………

Depth of Sample:…………………………………………..

Description of Sample:………………………………………………………………

Testes by :………………………………………………………………………………

Date:…………………………………………………

Determination No.	1	2	3
Can No.	47/47	01/01	BA/BA
Weight of can + moist soil, W_1 (g)	35.10	34.30	37.90
Weight of can +dry soil, W_2 (g)	33.90	32.90	36.30
Weight of can W_C (g)	26.60	25.70	28.50
Weight of water, W_w (g)	1.20	1.40	1.60
Weight of dry soil, W_s (g)	7.30	7.20	7.80
Moisture content, W (%)	16.44	19.44	20.51
PLASTIC LIMIT (%)	18.8		

Liquid limit = 28.0%

Plastic limit = 18.8%

Plasticity index = liquid limit – plastic limit 10.8%

APPENDIX B_0

LOCATION: BORI/RIVERS STATE

SAMPLE NO. A7

GRAIN SIZE ANALYSIS

NO.	SIEVE SIZE (MM)	Wt of SIEVE (mm)	Wt of SIEVE + SAMPLE	Wt of SAMPLE RETAINED (mm)	PERCENT RETAINED (%)	CUMMULATIVE PERCENT RETAINED (%)	PERCENTAGE PASSING
4	4.750	483.20	492.00	8.8	2.108	2.108	97.890
10	2.000	401.79	532.00	130.21	31.100	33.298	66.702
30	0.600	501.58	669.00	167.42	40.108	73.406	26.702
50	0.300	314.01	387.00	72.99	17.485	90.891	26.590
100	0.150	291.30	321.00	30.00	7.190	98.081	9.110
200	0.075	291.00	294.00	3.00	0.718	98.799	1.910
RECEIVER	PAN	264.88	269.00	5.00	1.190	100.00	1.200