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Research Article

Effect of Crude Oil Contamination on Compaction and Consistency of Some Clay Soils from Parts of Yenagoa, Bayelsa State, Nigeria

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Abstract

Bayelsa state is the southernmost part of the crude oil prolific Niger Delta region of Nigeria where oil exploration and exploitation activities have resulted to the pollution of its land, water, and air. Most parts of the area have experienced crude oil contamination of one form or the other, and the effects on man and the ecosystem are wide ranging. This study has examined the effect of oil contamination on the compaction behaviour of two clay samples obtained at shallow foundation depths in Yenagoa. The two clay samples, A and B are classified according to the unified soil classification system (USCS) as high plasticity inorganic sandy fat clay, and sandy lean clay, respectively. 4, 8, and 12 % crude oil by mass of dry soil were used to mix with the soil samples and left to cure in plastic bags for 48 hours before testing. In sample B, liquid limit (LL) was found to increase by about 9% for all proportions of crude oil while plastic limit (PL) was increased by 13%, 15%, and 27% for 4, 8, and 12 % oil content, respectively. These increase in LL and PL also brought about an increase in plasticity index except for 12% crude oil treatment. However, in all, a low plastic soil was changed to a slightly high plastic one as plotted on the Casagrande chart. The maximum dry density (MDD) of the two samples was also reduced by oil contamination with an increasing oil content exacerbating the reduction of MDD. It is therefore, recommended that care be taken during construction when dealing with clay soils within a potential crude oil contaminated region.

Keywords

Crude Oil, Contamination, Compaction, Maximum Dry Density

1. Introduction

Clayey soils within Bayelsa State can be generally described as soft clays due to their loose structure and high compressibility. Therefore, for certain construction works to be safely and properly executed on/with these soils, an adequate assessment of the material property and an appropriate compaction of the soil must be carried out. However, material properties and compaction characteristics of any soil type may be controlled by different factors which can be broadly grouped into inherent factors (e.g., particle size distribution, consistency, and mineralogy) and secondary factors (e.g., ecological/environmental changes, and testing method). In Bayelsa State, the most ecological changes may result from contamination of the ground by petroleum hydrocarbon because of frequent crude oil spillages.

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Bayelsa State is an oil-rich region within the Niger Delta Basin of Nigeria where crude oil exploration and exploitation activities are common with an attendant environmental degradation of the region [13]. The degradation mainly results from crude oil spill and contamination of the soil, water, and air. In Nigeria's Niger Delta, where several oil pipelines are dispersed, there are a variety of reasons why oil spills occur. These pipelines may leak crude oil accidentally, on purpose, or a mix of the two. While oil thieves intentionally destroy oil pipelines via a practice known as bunkering, unintentional spills may happen when old pipes collapse. Additional factors contributing to hydrocarbon pollution in the area could be gas flaring, oil waste disposal, washings from marine vessels, run-off from oil-contaminated areas, refinery discharges, well blowouts, and maintenance mistakes [2, 7]. When crude oil leaks into the environment, it affects the aquatic, soil, and air systems. Crude oil spills have been shown to negatively impact plant development and soil quality [14]. Das [10] suggests that the impacts of crude oil pollution on the geotechnical engineering qualities of soil should be explored, given the significance of soil in the building sector.

Ite et al. [16] reported that there are more than 2,000 sites in the Niger Delta region that are contaminated with crude oil. Additionally, Nwilo and Badejo [19] and Ambituuni et al. [3] reported that since the beginning of the oil and gas industries in the region, oil spills have produced approximately 13 million tons of hydrocarbons due to well blowouts, pipeline wear and tear, and sabotage. Typically, the concentration of contaminated locations varies. A 2011 UNEP research suggests that crude oil concentrations in certain severely polluted places (like Ogoniland) may exceed 139,000 mg/kg. These have an immediate effect on the health and well-being of local residents and have an influence on soil, water supplies, and air quality, especially in areas without alternate drinking water sources [11, 18, 22].

Investigation of oil spill impacts in the Niger Delta region of Nigeria so far has largely been narrow to environmental and health concerns. However, apart from the environmental issues, such as groundwater pollution, the modification of geotechnical characteristics of oil contaminated soil is another matter for concern. Although researchers have extensively studied the properties of contaminated soils and have agreed that contamination alters the geotechnical properties of soil [1, 6, 15, 17, 20, 21]. However, its impact is not yet being well evaluated. The present study aims to investigate and evaluate further, the impact of controlled crude oil contamination on the compaction characteristics and soil consistency of some clay soils in Yenagoa Local Government Area of Bayelsa State in order to design safe and durable infrastructure in the region. The advantage of studying controlled contaminated samples is that it enables comparison of pre- and post- contamination properties.

2. Methodology

2.1. Sample Collection

Large amounts of soil samples (A and B) were retrieved at two different locations, from depths between 1ft and 2ft below ground surface, which is commonly the foundation level for shallow foundations in Bayelsa State. Sample A was collected at latitude 4.938901°N and longitude 6.36203°E (site 1 (S1)) in Edepie community while Sample B was collected at latitude 4.870479°N and longitude 6.284853°E (site 2 (S2)) in Azikoro community, all in Yenagoa metropolis as shown in the Figure 1 below.

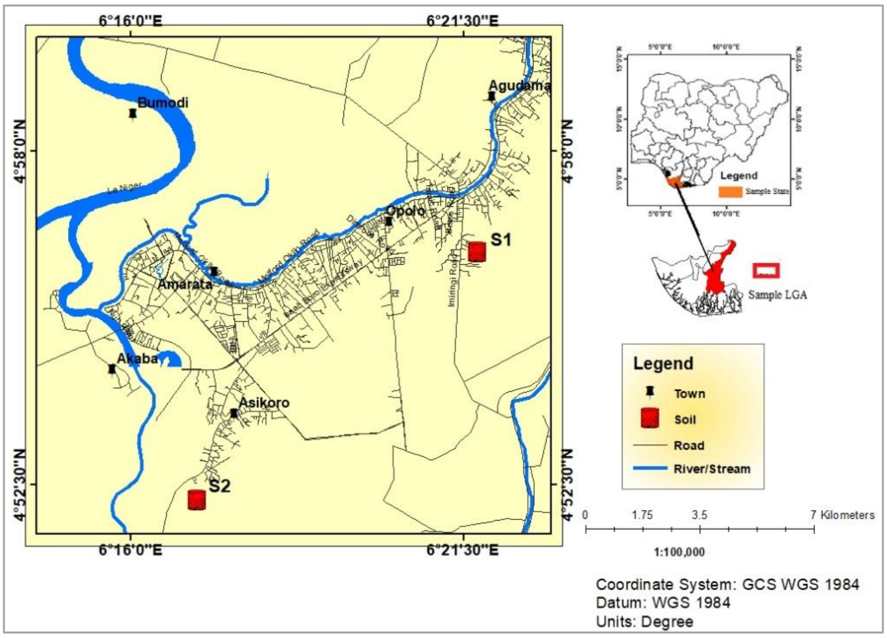

Figure 1. Study location and sample points.

Sample collection was done by hand digging with a spade and retrieved samples were transported to the laboratory stored in plastic bags. The Figure 2 below shows the processes of sample collection.

a b c

Figure 2. Processes in the sample collection: a, clearing and removing topsoil to reach desired depth b, measuring depth reached c, bagging of samples.

2.2. Sample Preparation

Soil samples were air-dried for several days until they became dry and then pulverised. Each sample was thereafter divided into two portions after vigorously and carefully mixing to attain homogeneity. One portion was used to investigate pre-contamination geotechnical properties while the other portion was for crude oil contamination and post contamination geotechnical investigation (Proctor compaction and Atterberg limits). Samples were mixed with randomly chosen proportions of 4%, 8%, and 12% crude oil by mass of dry soil, and allowed 48 hours in sealed plastic bags to attain homogeneity before testing.

2.3. Geotechnical Testing

Particle size distribution (PSD) test was carried out in accordance with ASTM D422 [4]. The dry sieve method was adopted with a mechanical shaker used. Shaking was done for ten minutes before disassembling stacked sieves and measuring retention for each sieve size. The test was repeated three times for comparison to ensure reproducibility of test. Where results were comparable, simple average was taken.

Atterberg limits consisted of liquid limit (LL) and plastic limit (PL). These tests were carried out in accordance with the BS 1377:1990 [8] parts 1 and 2. The Casagrande apparatus method for LL and rolling method for PL were both done as prescribed by the relevant sections of the Standards.

Compaction was done to determine the moisture content versus dry density relationship of both uncontaminated and contaminated soil samples. This was carried out using the light (2.5 kg) proctor compaction method, in accordance with relevant sections of BS 1377:1990 [8] part 4.

3. Results and Discussions

3.1. Geotechnical Classification of Untreated Samples

The PSD, LL, PL, and PI of the sample were determined. Results are presented as Figure 3 (PSD) and Figure 4 (plasticity) below.

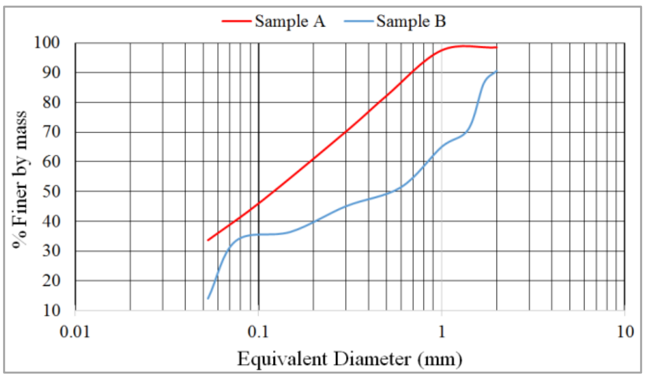

Figure 3. Particle size distribution of samples A and B.

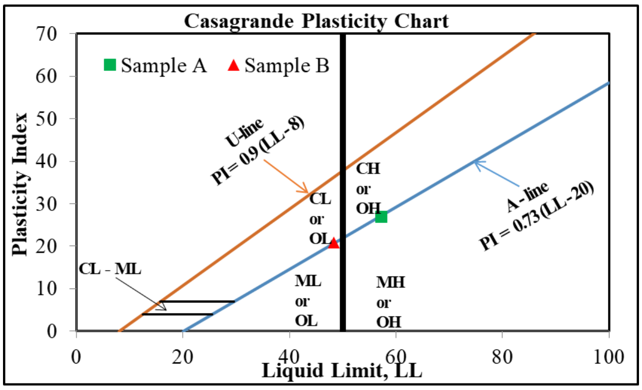

Figure 4. *Classification of samples A and B.*

For Sample A, the PSD curves in Figure 3 show that Sample A is poorly graded (gap), fine-grained having particles ranging in size from 2 mm down to silt-clay size. About 40% of the soil falls within the silt-clay range with the remaining being fine sand, which makes it a sandy silty clay soil.

The plasticity index – liquid limit relationship (Casagrande plasticity chart), which is used to classify soils according to the unified soil classification system (USCS) [5] has been adopted here. In the Figure 4, Sample A falls almost on the "A-line" on the right-hand side of the Casagrande chart, suggesting a high plasticity inorganic sandy fat clay. A further classification using the American Association of State Highway and Transportation Officials (AASHTO) system identifies the soil to be a clayey soil (A-7-6). Additionally, applying a group index (GI) concept for qualitative evaluation of the desirability of sample A as a highway subgrade material, using the Equation 1 [9] below consequently presented the soil as A-7-6(8), which is considered as a fair to poor subgrade material.

$$GI = (F_{200} - 35)[0.2 + 0.005(LL - 40)] + 0.01(F_{200} - 15)(PI - 10) \quad (1)$$

Sample B has about 32% of silt-clay particles (Figure 3) and ranges from 2mm downward. Based on the PSD curve, this sample can be classed as a gap graded clayey sand. However, adopting the USCS [5], this sample (see Figure 4) having an LL less than 50% and a PI greater than 7% can best be classified as a sandy lean clay despite less than 50% particles passing the No. 200 sieve (74 microns). According to the AASHTO system, sample B is A-2-7 (silty or clayey sand). Applying the GI concept for qualitative evaluation of the desirability of sample B as a highway subgrade material presents it as A-2-7(2), which is a subgrade rating of excellent to good [9].

3.2. Compaction Properties of Untreated Samples

The moisture content – dry density relationships of the studied samples are shown in Figure 5. For sample A, about 28% moisture content was sufficient to achieve its maximum dry density (MDD), which lies at about 1.55 Mg/m^3 as tested under the light (2.5kg) Proctor compaction. It can also be observed that there was a steady increase in dry density (DD) with an increase in moisture content on the dry side of optimum while a drastic reduction in DD occurs on the wet side of optimum. Sample B on the other hand demonstrates both a steady increase and decrease in DD on the respective sides of optimum. An OMC of about 15% was recorded to produce an MDD of 1.48 Mg/m^3.

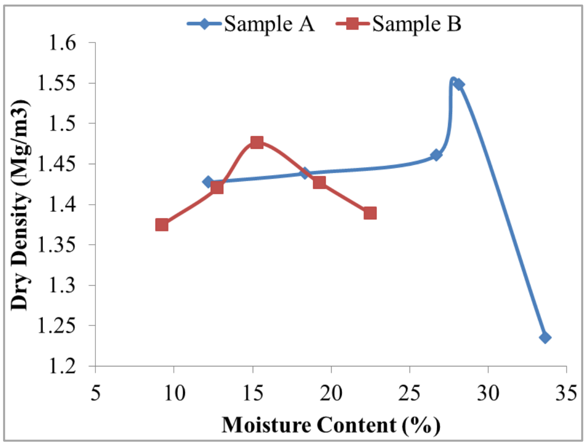

Figure 5. *Moisture content versus dry density relationship of untreated samples.*

3.3. Impact of Crude Oil Contamination on Geotechnical Properties

3.3.1. Index Properties

A clear impact of crude oil contamination on the plasticity of sample B is demonstrated in Figure 6. The sample which originally was a low plastic soil has been transformed to a slightly high plastic one by contamination irrespective of the amount of oil. Both PL and LL were increased by the introduction of crude oil. However, varying the amount of crude oil in the sample significantly controls the PL but did not meaningfully affect LL. A higher oil content yielded a higher PL as shown in Table 1, which is in conformity with the works of Karkush and Kareem [17] and Elisha [12].

Table 1. *Plasticity variations with crude oil contamination of Sample B.*

% Crude Oil	LL (%)	PL (%)	PI (%)
0	48.30	27.51	20.79
4	52.4	31.0897	21.3103
8	52.6	31.6537	20.9463
12	52.4	34.986	17.414

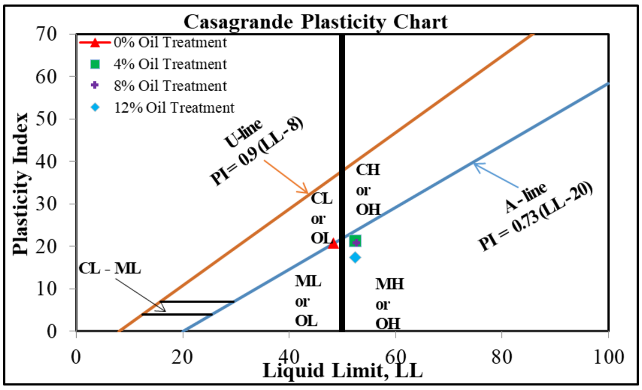

Figure 6. Effect of crude oil contamination on plasticity of Sample B.

3.3.2. Compaction Properties

The moisture content versus dry density curves presented in Figure 7 and Figure 8 for samples A and B, respectively have demonstrated diverse characteristics in terms of the relationship between amount of moisture content and dry density. A distinctive trend cannot be accorded the curves as per the influence of oil contamination on the behaviour of either sides of optimum moisture content.

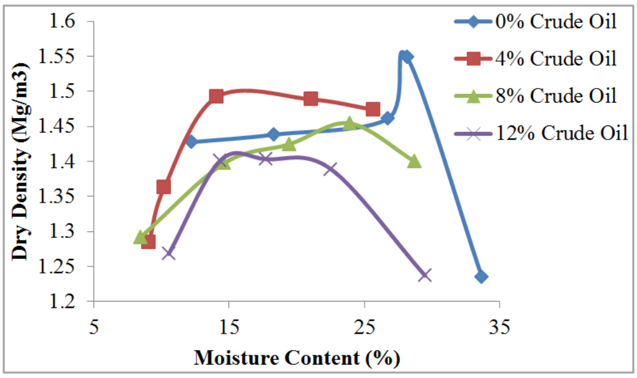

Figure 7. Crude oil contamination and compaction characteristics of Sample A.

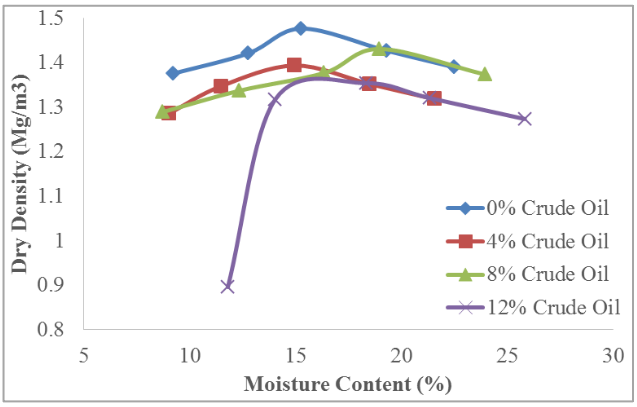

Figure 8. Crude oil contamination and compaction characteristics of Sample B.

Nevertheless, oil contamination is generally seen to reduce OMC and MDD in both soil samples (Figure 9 and Figure 10, respectively) except for the OMC of sample B. While these trends are valid, Rajabi and Sharifipour [20] have shown that the influence of crude oil contamination on clays can be diverse, identifying volume of oil used, soil type and type of hydrocarbon as critical factors that determine such influence. Considering the importance of dry density in controlling soil strength and permeability, care must be taken to ensure sufficient dry density is achieved during construction, and where oil contamination prevents it, alternative approaches be considered. These may range from remediation to ground improvement.

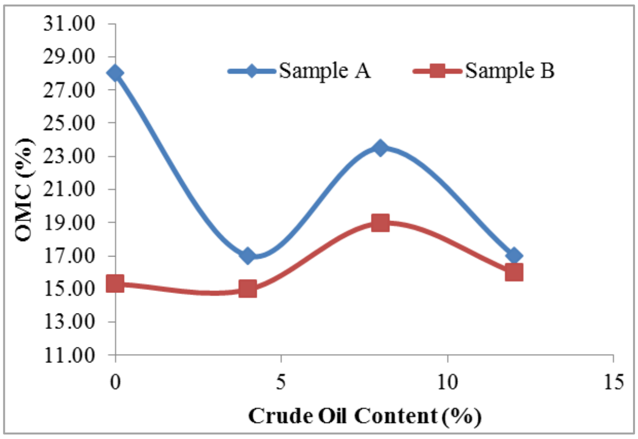

Figure 9. Effect of crude oil on OMC.

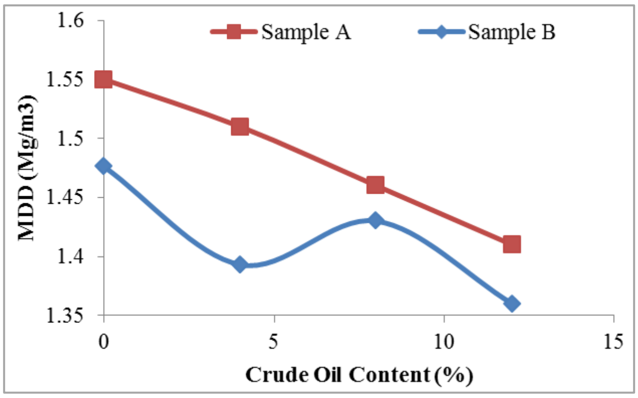

Figure 10. Effect of crude oil on MDD.

4. Conclusions

This study considered the role of crude oil contamination on the compaction behaviour of clay soils and has concluded that the contamination of clay soils with crude oil can be inimical to their performance. The maximum dry density of clay soils is reduced by oil contamination. Dry density is a critical parameter that controls soil strength and permeability; therefore, it is important that measures are considered during construction to achieve sufficient soil density, and where oil contamination prevents it, alternative approaches be considered. These may range from remediation to ground improvement.

Likewise, the consistency limits of clay soil can also be altered by oil contamination. Although just one of the samples was examined, it was clear that liquid limit and plastic limit of the clay soil were reduced and plasticity index increased, by the crude oil infiltration.

Abbreviations

AASHTO: American Association of State Highway and Transportation Officials
ASTM: American Society for Testing and Materials
BS: British Standards
DD: dry Density
GI: Group Index
LL: Liquid Limit
MDD: Maximum Dry Density
OMC: Optimum Moisture Content
PI: Plasticity Index
PL: Plastic Limit
PSD: Particle Size Distribution
USCS: Unified Soil Classification System

Conflicts of Interest

The authors declare no conflicts of interest.

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