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The Effect of Oil Pollution on the Engineering Properties of Construction Soils in Some Selected Oil Region of Nigeria: A Case Study of Four Oil Towns in Rivers and Delta States

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ABSTRACT: The nature of subgrade as well as basic information of soils for construction purposes is important for engineers, especially civil engineers and the general public. The primary aim of this research work is therefore to access the effect of oil spillage on the engineering properties of soils around the oil producing states of Nigeria. Four communities in two state of the Niger- Delta region of Nigeria were selected for investigation. These communities include Alesa (as sample A) and Aleto (as sample B) in Rivers state and Elume (as sample C) and Mereje (as sample D) in Delta state of the Niger- Delta region of Nigeria. Soil samples from these communities were collected at the subgrade depth of the oil spilled soils and was later subjected to laboratory examination. Important soil properties that were evaluated through laboratory investigation include soil shear strength test using triaxial test where the shear strength parameters were determined to enable evaluation of soil bearing capacity using Terzaghi's equations. Others include soil strength (CBR) test, soil permeability test, and soil classification test as well as soil compressibility tests or one dimensional consolidation test. The results show that the oil pollution/ spillage have affected the engineering properties of construction soils in the four towns investigated to some degrees. The California Bearing Ratio (CBR) value of the subgrade, the Coefficient of Volume Compressibility,Mv, the Safe Bearing Capacity and the Coefficient of Permeability, K of the investigated soil , all fall below the accepted standard limit for soils to be used for construction purposes. This result will hopefully add to the existing knowledge as well as equipping the government and other relevant agencies for policy and regulatory development for the oil and gas, and construction industries for the sustenance of economic development in Nigeria. Therefore, before any meaningful civil engineering construction works can be done in these communities, the soils within the area will have to be subjected to series of engineering soil tests so as to equip the government and other interesting stakeholders with the requisite knowledge on how to apply appropriate soil remediation and soil stabilization techniques.

KEYWORD: Oil Spillage/Pollution, Construction Soils, Terzaghi's Bearing Capacity, Soil Strength Test, Coefficient of Volume Compressibility, Permeability Coefficient ,K.

1. INTRODUCTION

Since the discovery of oil in Nigeria which has changed the political, economic, and business landscape of the nation, there have been associated environmental and social-economic problems. There is no doubt that Nigeria is still one the biggest oil producing country in Africa and one of the key players in the organization of petroleum exporting counties (OPEC). All oil producing region of Nigeria are richly endowed with abundant natural resources which used to generate up to seventy percent of the nation's foreign exchange earnings.

Ironically, in spite of the increasing revenue from crude oil exploitation, the towns from which this resources flow in the oil producing states continue to live in conditions of socio-economic deprivation, including shortage of basic amenities and abject poverty. This has arguably led to some indigenes embarking on oil bunkering that has significantly affected Nigeria's oil production levels and hence the global oil market. In addition, the effect of oil spillage on soils, especially those used in road or building construction can directly or indirectly affects human being. As we know, there are three basic needs of man- shelter, air and water (food). Basically, oil spillage can affect all these three basic needs because its effects can pollute the air, the water as well as the soil in which nearly all constructions take place, including buildings for shelter. But our main interest here is to access the effect of oil spillage on construction soils.

To begin with, oil spill is common fallout of oil exploitation and exploration in the Niger Delta region. Oil spills include any spill of crude or oil distilled products, example gasoline, diesel, fuels, jetfuels, and kerosene, hydraulic and lubricating oil. There have been an estimated total of over 7000 oil spill incidents reported over a 50 year period. Oil spills has both short term and long term effects.

It is an established fact that nearly all civil engineering projects are built on to, or into, the ground (subgrade). Smith and Smith (1998), emphasized that the nature of the soil (subgrade) at any project location, be it a structure, a roadway, a tunnel or a bridge, should be of great importance to the civil engineer. It is important to note that the subgrade is a layer of natural soil prepared to receive the other layers of the pavement in case of road pavement or foundation, in case of other civil engineering structures. However, when the soil/subgrade is affected by the oil spill, water absorption is prevented by the soil. Thus, soil test/ site investigation is a prerequisite activity before any structure is erected, especially in the Niger Delta region. Therefore, the importance of the soil tests to evaluate the supporting power of subgrade in the Niger region of Nigeria cannot be over-emphasized. According to Gupta and Gupta (2008), the inadequate stability of the subgrade may be attributed due to the inherent weakness of the soil itself, excessive moisture in the subgrade, as well as inadequate compaction of the subgrade. As a result, important properties of the soil that can be evaluated include bearing capacity, soil strength, compressibility, classification and permeability.

Bearing capacity of soil is the maximum load per unit area. It is evaluated using Terzaghi’s equation. Through triaxial test, shear strength parameters are determined which constitute part of Terzaghi’s equation. The major soil strength of importance here is the California Bearing Ratio (CBR) test. The procedure for this test is described in the next section. The major aim of the compressibility test or one dimensional consolidation test using the oedometer is to determine the coefficient of volume compressibility as well as predicting the total consolidation settlement of the soil in question. The major soil classification tests involved are the Atterberg Limit Tests (Liquid Limit Test and Plastic Liquid Limit Test) and the Sieve Analysis/Particle Size Analysis tests. The ease which water flows through a soil is quantitatively expressed in terms of permeability, K. According Garg (2005), the determination of permeability of a soil is extremely important to estimate the seepage forces, which has a direct effect on the safety of the hydraulic structures. Again, in compression test (unconfined), the value obtained is used to check the short-term stability of foundations and earthen slopes; and sensitivity of the day. Therefore, the conduct of these tests on the soil specimens obtained from Alesa (sample A) and Aleto (sample B) in Rivers state and Elume (sample C) and Mereje (sample D) in Delta state of the Niger-Delta region will highlight whether such soils meet up with the required strength for foundation of structures to be built. It is obvious that when the required strength cannot be obtained, definitely this will affect the cost and safety of building in such locality. All stages of oil exploitation impact negatively on the environment. However the greatest single intractable environmental problem caused by crude oil exploration in the Niger-Delta region is oil spillage (Enujiugha and Nwanna, 2004). The environmental consequences of oil pollution on the inhabitants of Niger Delta region are enormous. According to Ironi and others (2006) oil spills affect the physiochemical properties of the soil such as temperature, structure, nutrient status and pH. Consequently, most agricultural lands have been degraded and productive areas turned into wastelands. Thus with increasing soil infertility due to the destruction of soil micro-organisms, and dwindling agricultural productivity, farmers have been forced to abandon their land to seek non-existent alternative means of livelihood. This recent research work therefore presents the assessment of the effects of oil pollution on the engineering properties of construction soils of the selected communities (Alesa and Aleto in Rivers state and Elume and Mereje in Delta state) of the Niger region of Nigeria. Owing to the peculiar nature of this subject matter, many researchers have ventured into one aspect of related research work or the other, but none has addressed the subject matter wholly. For example, Worgu (2000) investigated the adverse environmental effect that crude oil exploitation had on soils, forest and water bodies in host communities in the oil producing states of Nigeria. In his assessment, farmers have lost their lands and are forced to emigrate to other communities in search of livelihood, thereby exerting additional pressures on natural resources in such areas. The works of Agunwamba and others (2002) concentrated on the aquatic environment. Abil and Nwosu (2009) investigated the effect of oil spillage on the soil of Eleme in Rivers state of the Niger- Delta Area of Nigeria. Their research area was basically to determine the acidic nature of the soils at Ogale and Agbonchia. Nwachukwu and others (2019) examined the engineering properties of crude oil contaminated clay soil in the Niger- Delta Area of Nigeria. Their major focus was on oil contaminated soils in Akiogbologbo Engenni Ahoada LGA of Rivers state. The major focus of the works of Ekundayo and Obuekwe (2000) was on the physic-chemical analysis of soil samples at an oil spill site to determine the hydrocarbon content of top soil. Iloeje and others (2015) assessed the impact significance oil spill on the social-economic life of Mgbede people in Rivers state of the Niger-Delta Region of Nigeria. Wekpe and Mgbengasa (2016) investigated the effect of oil spill on soil quality in a tropical Deltaic Environment of South- South, Nigeria. Ejeh and Uche (2009) investigated the effect of Crude Oil Spill on Compressive Strength of Concrete Materials. In their contribution, Ledogo and others (2011) investigated the engineering properties of Bori Lateritic soil in the Niger-Delta Region of Nigeria. Finally, Onwuka and others (2021) carried out a pollution studies on soils from crude oil producing areas of Rivers state of Niger- Delta Region of Nigeria. Their area of interest was with regard to pure and industrial chemistry research focus. From the information highlighted so far, there is enough evidence that nothing or little has been comprehensively done to address the subject matter. It is therefore noteworthy, that the reviewed studies have not really addressed the subject matter fully. Henceforth, the need for this present research work.

2 .METHODOLOGY

2.1. Description of Study Area

The areas to be covered by this research work include four towns from two oil producing states in Rivers and Delta states affected by oil pollution. These communities/towns are Alesa and Aleto towns in Eleme local government area of Rivers state and Elume and Mereje towns in Sapele local government area of Delta state of the Niger- Delta region of Nigeria. Fig. I is map of Niger- Delta region of Nigeria showing the two study states.

Fig. 1: Map of Niger Delta Region of Nigeria showing the two study areas.

2.2. Data Collection And Material Sampling

This study was carried out in four selected oil producing host communities from two oil producing states of Rivers and Delta states affected by oil pollution. Soil samples were collected in four locations within the area of the corked oil well where massive crude oil spillage had occurred. Sample A is soil sample from Alesa, while sample B is the soil sample from Aleto. Similarly, sample C is the soil sample from Elume, while sample D is the soil sample from Mereje town. Samples/specimens were collected between 0 – 30 cm soil/subgrade depth. The soil samples were taken to the laboratory and were subjected to the appropriate analysis using appropriate procedures.

2.3. Methods

2.3.1. PROCEDURE FOR SOIL CLASSIFICATION TEST

The major soil classification tests involved are the Atterberg Limit Tests (Liquid Limit Test and Plastic Liquid Limit Test) and the Sieve Analysis/Particle Size Analysis tests. The brief procedures are shown under:

2.3.1.1. SIEVE ANALYSIS/PARTICLE SIZE ANALYSIS TESTS PROCEDURE

This method covers the quantitative determination of the particle size distribution in a soil down to the fine sand size. The procedures are described in BS 1377 (1975) part 2 and outlined by Nwachukwu and others (2022) as shown under.

Apparatus

a. BS test sieves as follows 75 mm, 63 mm, 50 mm, 37.5 mm, 28 mm, 14 mm, 10 mm, 6.3 mm, 5 mm, 3.32 mm, 2mm, 1.18 mm, 600 urn, 425um, 300 urn, 212 urn, 150 urn, 63um and receivers. **b**. A balance readable and accurate to 0.5g. **c**. A balance readable and accurate to 0.01g. **d.** A scope. e. A brush.

Test Procedure

a. 500g of the disturbed sub sample of the soil was collected and allowed to pass through series of different sieve sizes (as listed in the apparatus), by vigorous shaking at list 10 mm. **b**. The weight of soil retained on each sieve size was then weighed and noted and the corresponding mass of soil passing through each of the sieve was also noted.

c. The percentage of the soil passing through the sieve was calculated.

Calculation.

Let M = mass of the whole soil (total mass of soil), M_l mass retained an each sieve.

a For samples containing particles larger than 20 mm, in size the mass of material retained on each of the course series of sieves shall be calculated as a percentage of M, for example.

Percentage retained on 37.5 mm sieve = $M_l \frac{37.5mm}{M} * \frac{100}{1} =$ X **(1)**

b. The percentage passing for each sieve size (for 37.5 mm sieve) = 100 - X. **(2)**

c. The cumulative percentages by mass of the sample passing each of the sieves was computed and recorded.

Graph

a The graph of percentage passing was plotted against size of soil particles in millimeters (sieve sizes).

b. Thereafter, the soil was then classified as being clays, silt, sand, gravel or combined silt and day.

2.3.1.2. ATTERBERG LIMIT TESTS

This test, according to Clanville, (1952) covers the determination of the plasticity characteristics of soil, which are liquid limit, plastic limit, plasticity index and liquidity index. The test is also known as consistence test and can be performed in accordance with BS 1377 Part 2

(A) LIQUID LIMIT TEST USING CASSAGRANDE APPARATUS.

Apparatus

The following apparatus are usually used:

a. A flat glass plate (10 mm thick and 500mm square).**b.** Two palette Knives. **c**. A mechanical device. **d.** A grooving tool and gauge **.e.** A 150mm diameter-evaporating dish..**f.** Moisture content tins/cans. **g**. A beaker, containing distilled water. **h.** A non-corrodible airtight container, which was large enough to take about 200g to 250g of wet soil.

Test Procedure

a. 200g of the sample, passing through the 425um BS test sieve was collected, placed in the flat glass plate and mixed thoroughly with distilled water using the palette Knives, until the mass becomes a thick homogenous paste

b. A portion of the mixed soil was placed in the cup (the cup resting in the base) leveled off parallel to the base, and divided by drawing the grooving tool along the diameter through the center of the hinge, at the same time holding it normal to the surface of the cup with the chamfered edge facing in the direction of movement.

c. The crank was turned at the rate of two revolution per second, in which the cup was lifted and dropped until the two parts of the soil come into contact at the bottom of the groove along a distance of 13 mm

d. The numbers of blows at which this occurs was recorded for each trial.

e. Thereafter, a little extra of the soil mixture was added to the cup and mixed with the soil in the cup.

f The operations above were reported until two consecutive runs gave the same number of blows for closure.

g. A potion of the soil in the cup was collected for moisture content determination.

h. The procedures above were repeated at intervals as the sample changes from wet to dry.

Calculations

Let W = moisture content, W_i = weight of tin, W_2 = weight of tin plus wet soil, W_3 = weight of tin plus dry soil. Thus,

$$W = \frac{W_2 - W_3}{W_3 - W_I} \quad (3)$$

Plotting of Curves

a The relationship between the moisture content and the corresponding number of blows were plotted on a semi-logarithmic graph, with the percentage moisture as ordinates on the linear scale and the number of blows as abscissa on the logarithmic scale.

b. The best straight-line fitting the plotted points was drawn through them.

c. The liquid limit, LL is the moisture content, which corresponds to 25 blows on the group.

(B) PLASTIC LIMIT TEST USING CASSAGRANDE METHOD.

This test covers the determination of the moisture content at which the soil is plastic.

Apparatus

The following apparatus were used:

a. A flat glass plate. **b**. Two palette Knives. **c**. Moisture content can. **d**. A length of metal rod 3 mm in diameter and about 100 mm long.

Test Procedure

a. 20g of the air dried sample passing the 425m BS test sieve, was collected, mixed thoroughly with distilled water on the glass plate until it becomes homogenous and plastic enough to be shaped into a ball.

b. Thereafter, the ball of soil was mounded between the fingers and rolled between the palms of the hands until the heat of the hand has dried the soil sufficiently for slight crack to appear on its surface.

c. The mounded soil was rolled into thread of about 6 mm in diameter between the first finger and the thumb of each until the diameter reduced to about 3 mm and started to crumble.

d. The portion of the crumbled soil tread was gathered and transferred immediately to the moisture can.

e. This process was repeated for other part of the soil sample and their moisture content determined and recorded, using Eqn. (3).

f. The plastic limit is the average of the moisture contents at which the soil crumbles.

2.3.1.3. METHOD OF SOIL CLASSIFICATION/ DESCRIPTION

The following steps were adopted when classifying the soils.

a. **Grading of a distribution**: The soil was described as well graded, if the shape of the grading curve is too steep and is more or less constant over the full range of the soils particle sizes, such that the particle size distribution extends evenly over the range of the particle size within the soil; and there is no deficiency or excess of any particular size. Any other type of curve is described as poorly graded (Uniformly or gap graded).

b.. **The Uniformity Coefficient, Cu:** This is given by

$$Cu = \frac{D_{60}}{D_{10}} \quad \textbf{(4a)}$$

Where, D_{60} and D_{10} are effective size of the distributions of the curves. Note that:

i. If Cu < 4.0, then the soil is uniformly graded.

ii. If Cu > 4.0, then the soil is either well graded or gap graded and a glance at the grading curve should be sufficient for the reader to decide which the correct description is.

Knowing the liquid limit and plasticity index of the soil, the soil group symbol is then obtained using Table 1.1 and Fig.1.7 of Smith and Smith (1998) and BS 5930 (1981). Note that the plasticity index of the soil is obtained using Eqn.(4b).

Plasticity index, P.I. = Liquid limit(LL) - Plastic limit (PL) **(4b)**

2.3.2. PROCEDURES FOR CALIFORNIA BEARING RATIO (CBR) TEST

The procedures of determining the CBR of soil samples are outlined in BS 1377 part 5. In general, this method covers the determination of the California Bearing Ratio (CBR) of a soil, which is obtained by measuring the relationship between force and penetration when a cylindrical plunger of cross-sectional area 1935 mm^2 is made to penetrate the soil at a given rate. At any value of penetration, the ratio of the force to a standard force is defined as the California Bearing Ratio (CBR). The general procedures are as described under.

Apparatus

The following apparatus was used:**(a)** 20 mm BS test sieves, **(b)** A cylindrical metal mould of an internal diameter of 152 mm and an internal effective height of 127 mm, with detachable base plate and top plate and a collar.**(c)** Three metals plugs 150 mm in diameter and 50 mm thick, for static compaction of a soil specimen.**(d)** A cylindrical metal plunger .**(e)** A machine for applying the test force through the plunger consisting of a force — measuring device and means for applying the force at a controlled rate. **(f)** A means of measuring the penetration of the cylinder into the specimen and enabling the rate of penetration to be controlled. **(g)** A metal rammer. **(h)** A compression machine for static compaction.**(i)** An electric vibrating hammer.**(j)** A steel rod 15mm to 20mm in diameter and 4 10mm long.**(k)** A steel straight edge. **(1)** A spatula having a steel blade approximately 100mm x 20mm. **(m)** A means of measuring the movement of the top of the top of the specimen during soaking.**(n)** A balance weighing up to 25kg readable and accurate to 5g. **(o)** Apparatus for moisture content determination.

Test Procedure

a). The soil samples sub-grade or sub-base or base course were obtained, dried and allowed to pass through a 20mm BS sieve. **(b)** 5000g of the sample passing through the 20mm BS sieve was collected, mixed with 2 percent of water.

(c) The already mixed simple were divided into five parts in which one-fifth was poured into the already assembled mould and compacted under 25 blows using 4.5 kg rammer.. **(d)** The remaining parts of the mixed sample were poured accordingly into the mould and compacted as before.**(e)** The mould and the compacted soil sample were weighed on a weighing balance and their weights obtained and recorded. **(f)** Next, the soil sample contained in the mould was taken to the CBR equipment for strength determination.**(g)** There after a representative fraction of the compacted soil was taken and put into moisture can for moisture content determination.**(h)** This procedure was repeated for 4%, 6%, 8% , 10% up to 16% of H_20 (as the case may be) for different sample of soil.**(i)** In each case, let M_1 weight of mould plus soil sample. M_2 weight of mould and M_3 = weight of soil in mould (all in gram, g)

Thus,

i.. Bulk (wet) density of soil, p = $\frac{M_3}{Volume\ of\ mould}$

(5)

Where, Volume of mould, V = $\frac{\pi d^2 x\ 152^2 x\ 127}{4}$ = 23 x106 mm^3 **(6)**

ii. Moisture content is obtained using Eqn.(3)

iii.. Then, Dry density, ρd = $\frac{\rho}{I+W}$

(7) Where, w = moisture content

(j). Also, for each soil sample, let the dial reading corresponding to 2.5 mm Penetration and5.0 mm penetration be P and Q respectively. The plunger force at 2.5 mm and 5.0 mm penetration are taken as 13.34KN and19.96KN respectively then, the CBR for each trial is computed using Eqn.(8)

$$CBR = Maximum \begin{cases} \frac{Px}{13.34} X\ 100 \\ \\ \frac{Qx}{19.96} X\ 100 \end{cases} \quad \textbf{(8)}$$

Where, x Proving ring factor of the machine taken as 0.0434.

(k). The results so far obtained for each trial are then tabulated.

(I). Next, the graphs of dry — density against moisture content and CBR against moisture content are plotted on the same sheet.

(m). Finally, the moisture content (optimum moisture content) at which maximum dry density (MDD) occurred on the graph is located and traced to intercept with the CBR curve. This point of interception, when read off gives the CBR value of the soil sample.

2.3.3. PROCEDURES FOR TRIAXIAL TEST

The main purpose of carrying out the triaxial test in this research work is to determine the shear strength parameters, ϕ and C. ϕ is the angle of shearing resistance while C is the unit cohesion of the soil. Determination of these parameters will enable the evaluation of the bearing capacity of the subgrade (prior foundation), using Terzaghi's equation.

SHEAR STRENGTH USING TRIAXIAL TEST

The test procedures are described by Smith and Smith (1998) and Garg (2005) and involve plotting of Mohr circle in order to determine the shear strength parameters. In a nutshell, the Terzaghi's equation for bearing capacity of a foundation, assuming strip footing (foundation) is given by

$$Q_u = CN_C + \gamma ZN_q + 0.5\gamma BN_\gamma \quad \textbf{(9)}$$

The Terzaghi's bearing capacity coefficients, N_C, N_q and N_γ depend upon the soil's angle of shearing resistance and can be obtained from Table 1. Q_u is the ultimate bearing capacity . Z and B represent the depth and width of the foundation respectively while γ represent the unit weight of soil.

Then, the net ultimate bearing capacity of the assumed strip foundation is given by:

$$Q_u^{net} = CN_C + \gamma Z[N_q - 1] + 0.5\gamma BN_\gamma \quad \textbf{(10)}$$

And the safe bearing capacity of the assumed strip foundation is given by:

$$\text{Safe bearing capacity, } Q_s = \frac{Q_u^{net}}{F} = \underline{CN_C + \gamma Z[N_q - 1] + 0.5\gamma BN_\gamma} \quad \textbf{(11)}$$

F Where F is a suitable factor of safety.

Table 1: Terzaghi’s Bearing Capacity Coefficients.[Source : Smith and Smith (1998)]

ϕ	0^0	5^0	10^0	15^0	20^0	25^0	30^0	35^0	40^0	45^0
N_C	5.7	7.3	9.6	12.9	17.7	25.1	37.2	57.8	95.7	172
N_q	1.0	1.6	2.7	4.4	7.4	12.7	22.5	41.4	81.3	173
N_γ	0.0	0.5	1.2	2.5	5.0	9.7	19.7	42.4	100	298

Typical soil bearing capacity is shown in Tables 2a and 2b.

Table 2a: Typical Soil Bearing Capacity

S/N	**Soil Type**		**Safe Bearing Capacity (KPa)**
1.	Soft clay		**< 75**
2.	Firm clay		75 - 100
3.	Loose gravel		< 200
4.	Dense gravel		200- 600
			Allowable Bearing Capacity
5	Medium dense sand		100 to 300 KN/m^2
6	Loose sand		< 100KN/m^2 depend on degree of looseness
7.	Cohesive soils	Very stiff bolder clay and hand clay	300 to 600 KN/m^2
		Stiff clays	150 to 300 KN/m^2

Table 2b: ***Typical Soil Presumptive Safe Bearing Capacity***

S/N	**Type Of Soil**	**Presumptive Safe Bearing Capacity [KN/m^2]**
1.	Fine sand, silt	150
2.	Loose gravel, or sand gravel mixture	250
3.	Fine sand, loose and dry	100
4.	Soft slate, hard or stiff clay in a deep bed, dry	450

2.3.4. ONE DIMENSIONAL CONSOLIDATION TEST USING OEDOMETER

Here, the one dimensional consolidation test is performed in order to determine the coefficient of volume compressibility, volumetric change, etc. The test procedures are also described by Smith and Smith (1998) and Garg (2005). This is also known as soil compressibility test and is aimed at determining the coefficient of volume compressibility as well as predicting the total consolidation settlement of the soil in question. In a nutshell, after the loading has been completely removed, the final thickness of the sample can be obtained, from which it is possible to calculate the void ratio (e) of the soil for each stage of consolidation under the load increments. The graph of void ratio to consolidation pressure (p) can then be drawn. This is the e-p curve, typically shown in Fig.2

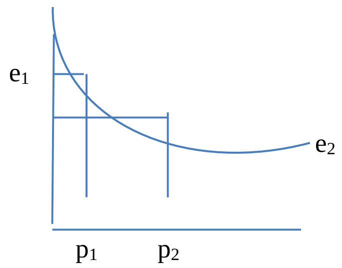

Fig.2: Void ratio to effective pressure curves[Source : Smith and Smith (1998)]

Then, the following calculations are fundamental:

i. VOLUMETRIC CHANGE

The volume change per unit of original volume constitutes the volumetric change. Thus, if a mass of soil of volume V_1 is compressed to a volume V_2, the assumption is made that the change in volume has been caused by a reduction in the volume of the voids.

Mathematically, Volumetric change, vc $= \frac{V_1 - V_2}{V_1} = \frac{[1+e_1] - [1+e_2]}{1+e_1} = \frac{e_1 - e_2}{1+e_1}$

12(a-c)

Where, e_1= void ratio at p_1 and e_2= void ratio at p_2. Now if the slope of the e - p curve is given the symbol ‘ a’, then,

$$a = \frac{e_1 - e_2}{p_1 - p_2} \text{ in m}^2\text{/kN} = \frac{de}{dp} \qquad \textbf{13(a-b)}$$

From the onset, e_1 can be computed using

$$e_1 = wGs \qquad \textbf{(14a)}$$

Where, w is the moisture content, and Gs is the specific gravity

Then, e_2 can be computed using:

$$e_2 = \frac{dH[1+e_1]}{H_1} + e_1 \qquad \textbf{(14b)}$$

ii. COEFFICIENT OF VOLUME COMPRESSIBILITY, M_V

This is sometimes called the coefficient of volume decrease, and the value represents the compression of a soil, per unit of original thickness, due to a unit increase in pressure.

Mathematically, **M_V** $= \frac{Volumetric\ change}{Unit\ of\ pressure\ increase}$

(14c)

But from Eqn. 12(a),Volumetric change $= \frac{V_1 - V_2}{V_1} = \frac{H_1 - H_2}{H_1}$

[as area is constant] $= \frac{e_1 - e_2}{1+e_1}$

15(a-c)

Where H_I and H_2 represent original thickness and final thickness respectively.

Then, from Eqn.(13), we have:

$$a = \frac{e_1 - e_2}{dp} \text{ and thus } e_1 - e_2 = adp$$

16(a-b)

$\Longrightarrow$ Volumetric change $= \frac{adp}{1+e_1}$ **(17)**

Therefore, from Eqn.(14), **M_V** $= \frac{Volumetric\ change}{Unit\ of\ pressure\ increase}$

$$= \frac{adp}{1+e_1} * \frac{1}{dp} = \frac{a}{1+e_1} \text{ in m}^2\text{/MN} \qquad \textbf{18(a-c)}$$

Typical values of M_V are depicted in Table 3

Table 3: Typical values of M_V [Source : Smith and Smith (1998)]

S/N	Soil Type	M_V (m²/MN)
1.	Peat	10.0- 2.0
2.	Plastic clay(normally consolidated alluvial clays)	2.0 – 0.25
3.	Stiff clay	0.25- 0.125
4.	Hard clay (boulder clays)	0.125- 0.0625

iii. TOTAL CONSOLIDATION SETTLEMENT, p_c

Once **M_V** is obtained, it is easy now to predict the consolidation settlement of the soil layer of thickness, H.

That is, Total Settlement pc = M_V dpH

(19)

2.3.5. PROCEDURES FOR SOIL PERMEABILITY TEST

The ease which water flows through a soil is quantitatively expressed in terms of permeability, K. This rate, K , is quite important to a civil engineer since in his work, he requires a soil which permits the flow of water through it. Hence, permeability becomes an important property of a soil, and needs to be studied thoroughly.

The procedure involved in the determination of K, either through constant head permeameter or falling head permeameter is outlined by Garg (2005) and the following calculations through Darcy’s law are fundamental.

DARCY’S LAW

The knowledge of the permeability of a soil enables an engineer to determine the quantity of water that can flow through the soil under a given set of boundary and hydraulic conditions. Darcy’s law states that:

$$Q = K * H_L * \frac{A}{L} = K*i*A$$

20(a-b)

Where $i = \frac{H_L}{L}$ = Hydraulic gradient

(21)

Then, $\frac{Q}{A} = K*I \Longrightarrow v = K*i$

22(a-b)

Where v = discharge velocity

If A_V = Area of voids, then $A_V * V_S = A*v$

(23)

Where V_S is the actual seepage velocity

Then, from Eqn.(23), $V_S = v * \frac{A}{Av} = \frac{V}{n} = \frac{V(1+e)}{e}$

(24)

Where, Q = discharge, V_S= Seepage velocity, v = discharge velocity, n = porosity and e = void ratio. Using constant head permeameter, then from Eqn.(20), K can be estimated as:

$$K = \frac{Q}{H} * \frac{L}{A}$$

(25)

But using falling head permeameter, K is estimated using Eqn. (26) as:

$$K = \frac{2.3aL}{At} Log_{10} \frac{H_1}{H_2} \qquad \textbf{(26)}$$

Where A is area, L is length, t is time, a is inside area of the burrette, H is the head difference.

Typical values of K are shown in Table 4

Table 4: Typical values of Permeability K [Source : Garg (2005)]

S/N	Soil Type	K is of the order of , in cm/ sec
1.	Gravel	10^1 to 1 (10^0)
2.	Coarse sand	$10^0 to\ 10^{-1}$
3.	Medium sand	$10^{-1} to\ 10^{-2}$
4.	Fine sand	$10^{-2} to\ 10^{-3}$
5.	Silty sand	$10^{-3} to\ 10^{-4}$
6.	Delhi silt	$7 * 10^{-5}$
7.	Boston blue clay	$6 * 10^{-7}$
8.	London clay	$1.5 * 10^{-9}$

3. RESULTS AND DISCUSSION

3.1. RESULT PRESENTATION

3.1.1. SOIL CLASSIFICATION TEST RESULTS

The procedures for the soil classification and description have been outlined in section 2.3.1. The audience is advised to consult the works of Nwachukwu and others (2022) to see the nature of sieve analysis graphs as well as the Atterberg limit plottings. In a nutshell, the results of the soil classification tests are depicted in Table 5.

Table 5: Soil Classification Test Results.

S/N	Sample	D_{10} (μm)	D_{60} (μm)	Uniformity coefficient, Cu from Eqn.(4a)	Nature of Grading Curve	P.I. (%)	L.L. (%)	Soil classification using Table 1.1 and Fig. 1.7 of Smith and Smith (1998)	Group Symbol
1.	**A.**	280	42000	150 > 4.0	Gap graded, Pg	7.5	28.6	ML	PgML
2.	**B.**	200	44000	220 > 4.0	Gap graded, Pg	18.0	40.4	MI	PgMI
3.	**C.**	179	2200	12.29 > 4.0	Well graded, W	6.9	21.8	SCML	WSCML
4.	**D.**	181	1975	10.91 > 4.0	Well graded, W	15.2	30.5	SCMI	WSCMI

3.1.2. SOIL STRENGHT TEST RESULTS SHOWING CBR , OMC AND MDD VALUES

The results of the California Bearing Ratio(CBR) tests as well as the Optimum Moisture Content(OMC) and Maximum Dry Density (MDD) are displayed in Table 6. All the procedures have already been described in section 2.3.3 and the nature of all graphs especially the combined CBR, Dry density and moisture content graph can be seen in the works of Nwachukwu and others (2022).

Table 6: Soil Strength Test Results Showing CBR , OMC And MDD Values

S/N	Sample	CBR Value (%)					Dry Density [DD] (g/cm^3)					Optimum Moisture Content [OMC] (%)	Maximum Dry Density [MDD] (g/cm^3)
		AT w =8 %	10%	12%	14%	16%	8%	10%	12%	14%	16%		
1.	A	8	7	8	6	7	1.61	1.67	1.82	1.89	1.80	14.2	1.89
2.	B	7	8	9	6	6	1.63	1.69	1.87	1.87	1.76	14.1	1.89
3.	C	9	6	7	7	8	1.42	1.48	1.60	1.69	1.59	14.0	1.70
4.	D	7	7	7	8	8	1.51	1.54	1.62	1.68	1.55	13.9	1.63

3.1.3. SOIL TRIAXIAL TEST RESULTS SHOWING SHEAR STRENGHT PARAMETERS AND BEARING CAPACITY VALUES.

Table 7 depicts the Soil Triaxial Test Results Showing Shear Strength Parameters And Bearing Capacity Values at depth, Z = 30cm , B = 1.5m and F = 3.00

Table 7: Soil Triaxial Test Results Showing Shear Strength Parameters And Bearing Capacity Values

S/N	Sample	Shear Strenght Parameters		Terzaghi's Bearing Capacity Factors From Table 1			B (m)	Z (m)	F	Q_U [KN/m^2] From Eqn.(9)	Q^{NET} [KN/m^2] From Eqn. (10)	Q_S [KN/m^2]	
		C [KN/m^2]	Φ (^{0})	N_C	N_q	N_γ						From Eqn. (11)	Remark
1.	A.	23.90	11.10	11.0	5.0	1.8	1.5	0.3	3.0	314.2	305.6	107.3< 150	Not Ok
2.	B.	25.85	11.41	11.2	5.3	1.9	1.5	0.3	3.0	346.8	341.1	119.4< 150	Not Ok
3.	C.	3.00	15.00	12.9	4.4	2.5	1.5	0.3	3.0	96.21	90.81	35.67< 150	Not Ok
4.	D.	2.00	10.00	9.6	2.7	1.2	1.5	0.3	3.0	49.98	44.58	20.26< 150	Not Ok

3.1.4. SOIL CONSOLIDATION TEST RESULTS FROM THE OEDOMETER TEST

The results of the oedometer test showing the volumetric change, vc , the Coefficient of Volume Compressibility, M_V , as well as the Total Consolidation Settlement, pc values are shown in Table 8

Table 8: Soil Consolidation Test Results From The Oedometer Test

Sample	A	B	C	D
w(%)	20	25	15	15
Gs	2.66	2.66	2.63	2.64
$e_1 = wGs$	0.53	0.67	0.40	0.40
H_1(mm)	18.1	18.3	18.0	19.0
H_2(mm)	19.0	19.3	18.9	20.0
dH(mm) = $H_1 - H_2$	-0.90	-1.00	-0.90	-1.00
e_2 from Eqn.(14b)	0.45	0.58	0.33	0.33

de = e_1 - e_2	0.08	0.09	0.07	0.07
p_1 (KN/m^2)	190	170	185	175
p_2 (KN/m^2)	270	270	195	275
dH (KN/m^2) = p_1 -p_2	100	100	100	100
vc from Eqn.(12c)	0.05	0.05	0.05	0.05
a(m^2/KN) from Eqn.(13b)	8E-4	9E-4	7E-4	7E-4
Mv(m^2/KN) from Eqn.(18c)	5.2E-4	5.4E-4	5E-4	5E-4
Pc (mm) from Eqn.(19)	1045.8	1077.8	1000	1000

3.1.5. SOIL PERMEABILITY TEST RESULTS

The results of the constant head and falling head permeability tests showing the coefficient of permeability; K is depicted in Table 9. Note , samples A and B were carried out using Falling Head Permeameter test while samples Cand D were carried out using Constant Head Permeameter.

Table 9: Coefficient of Permeability, K from Soil Permeability Test Results

S/N	Sample	L (cm)	A (cm^2)	H (cm)	H_1 (cm)	H_2 (cm)	Q (cm^3/sec)	t (sec)	a (cm^2)	K	
										From Eqn.(25)- Constant Head	From Eqn.(26)- Falling Head
1	**A**	15	20		35	15		350	1.0		1.8E-3
2	**B**	16	22		30	18		330	1.2		1.4E-3
3	**C**	14	80	12			6.5			9.5E-2	
4	**D**	15	85	13			7.1			9.6E-2	

3.2. RESULT DISCUSSION

In this work, the essential soil tests to determine the suitability of the engineering properties of the oil polluted soils of four communities in Rivers and Delta states , designated as sample A, B, C, and D to be used as construction soils has been carried out. These all important soil tests included the classification tests, the soil strength as the CBR test, the soil bearing capacity test through the triaxial test, the consolidation test as well as the permeability test. From the results presented in Table 5, sample A group symbol is **PgML,** meaning that it is predominantly gap graded silty soil with low plasticity. Sample B is designated as **PgMI**, showing that it is predominantly gap graded silty soil with intermediate plasticity. However, samples C and D soils have **WSCML and WSCMI** group symbols, indicating that they are well graded mixture of fine sand, silt and little clay. But while sample C is made up of low plasticity, sample D is made up of intermediate plasticity. The CBR results presented in Table 6 indicates that none of soil samples met with the minimum requirement of 10% CBR value for subgrade of flexible pavement construction, according to the federal highway manual of 1973. The results of the bearing capacities of the four samples are presented in Table 7. Using the safe bearing capacity as a guide, none of the four samples values exceeded 150KN/m^2. This shows a very weak value, meaning that the subgrade of the four samples may not sustain a foundation for a building, road construction, or any other civil engineering construction. Again, the results from the oedometer test (Table 8) show that coefficient of soil compressibility, M_v of all the four samples investigated are below the acceptable limit based on the type of soils investigated in this research work as indicated in Table 3. Finally, following the results of the permeability tests in Table 9, it can be envisaged that the ease of water passage through the soils for the four samples is close to normal but not too wonderful. The soil civil engineer planning to use these sites for construction will definitely use a very high level of discretion. It can be recalled that the safe bearing capacity is the maximum load per unit area which the soil can withstand without any displacement or settlement or shear failure. It is therefore suggested that the soils in the four oil communities investigated be subjected to civil engineering integrity tests before structures are built on them.

4. CONCLUSION AND RECOMMENDATION

4.1. Conclusion

So far in this work, the engineering properties of the oil polluted soils in Alesa (as sample A) and Aleto (as sample B) communities in Rivers state and Elume (as sample C) and Mereje (as sample D) communities in Delta state of the Niger- Delta region of Nigeria have been investigated and the results, within the limit of experimental error are displayed in the result and discussion session. It can be emphasized that the study of the engineering properties/behavior of the four samples is extremely important to civil engineers, because every engineering structure such as a building, a road, a bridge, etc, will have to be rested and founded on the ground. Thus, the strength of the soil to withstand loads under different site conditions therefore becomes an important factor, in designing safe foundation for any structure. From the works that have been done, it has been discovered that the oil pollution/ spillage has affected the engineering properties of construction soils in the four towns investigated to some degrees. Therefore, before any meaningful civil engineering construction works can be done, the soils within the area will have to be subjected to series of engineering soil tests.

4.2. Recommendation

It is expected that the results of this research work will hopefully add to the existing knowledge in the oil and gas industry as well as the construction and engineering world. The results will also equip the government and other relevant agencies for policy and regulatory development for the oil and gas, and construction industries for the sustenance of economic development in Nigeria. Therefore, before any meaningful civil engineering construction works can be done in these communities and other affected oil polluted towns, it is recommended that the soils within these areas will have to be subjected to series of engineering laboratory soil tests so as to equip the government and other interesting stakeholders with the requisite knowledge on how to apply appropriate soil remediation and soil stabilization techniques and subsequent reconstruction of these towns to allow for maximum safety of all civil engineering structures.

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