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Correlation between the Bearing Capacity of Crude Oil Contaminated Soil of Mgbede and the Percentage Contamination

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Abstract: This study was conducted in Mgbede, River State, Nigeria, hosting up to, or even more than 100 oil wells. It examined the relationship between the bearing capacity of crude oil contaminated soil and the percentage contamination. Four uncontaminated soil samples were randomly collected at 1.5 m depth within the oil field with hand auger and analyzed for the load bearing properties limited to cohesion, angle of internal friction and bulk density. With these parameters, the bearing capacity was determined for each sample. Crude oil, collected from one of the oil wells with viscosity 0.02611 poises at 40$^{.o}$C and specific gravity 0.8227 g/cm^3, was used as the contaminant. This was mixed with the soil sample at 5%, 10%, 15% and 20% concentrations. The mean values of the bearing capacity were 582.458 KN/m^2, 495.35 KN/m^2 for square and strip footings respectively at 0% contamination, 240.735 KN/m^2 and 204.753 KN/m^2 at 5%, 321.683 KN/m^2 and 274.593 KN/m^2 at 10%, 127.003 KN/m^2 and 109.12 KN/m^2 at 15%, 105.28 KN/m^2 and 90.758 KN/m^2 at 20% for square and strip footings, respectively. The results showed a consistent decrease in the load bearing values as the crude oil content increased. The result of the null hypothesis established a strong and significant relationship between the bearing capacity of crude oil contaminated soil and the percentage contamination.

Key words: Bearing capacity, contaminated soil, crude oil, percentage contamination.

1. Introduction

Since oil exploration and exploitation activities commenced in Nigeria, dating back to 1958, the host communities have suffered various forms of environmental problems involving social, economic, political, cultural and infrastructural decay in varying degrees and dimensions. Oil spill is one major source of these problems as it literally occurs at every stage of oil production process. When oil spills on land, the soil is generally contaminated. According to Colorado Department of Health and Environment [1], OCS (oil contaminated soil) is any earthen material or artificial fill that has human or natural alteration of its physical, chemical, biological or radiological integrity resulting from the introduction of crude oil, any fraction or derivative thereof (such as gasoline, diesel or used motor oil) or any oil based product. Oil is known to exert adverse effects on soil properties and plant community [2].

Spill may be accidental especially during transportation both on land and sea. It could also be due to leakage from storage tanks, pipelines or even during drilling operations. Some cases are attributable to sabotage or simply purposeful as in the Gulf War in 1991.

When an oil spills or leakage occurs, soils, water bodies and the air around the sources of leakage are contaminated. The extent of contamination depends largely on the chemical composition of the contaminants and the properties of the soil [3].

In Niger Delta, the intensive oil activities make the communities highly vulnerable and totally exposed to the hazards of environmental degradation occasioned by spilled hydrocarbon. Given the trend of incidents of oil spillage within the past 55 years of oil

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exploitation in the region, and the steady growth of more oil sites, oil spillage is expected to be substantially on the increase in spite of modern technologies in oil exploration and exploitation process. Land in these oil rich communities has been substantially degraded and devastated due to spill. This degradation resulting from oil and gas production has attracted the attention of environmentalists and other experts, Eregha and Irughe [4] quoting from Ref. [5].

While a lot of studies have been done and documented on the impact of crude oil spill on soils, the relationship between the soil strength parameters and the percentage contamination has not been sufficiently explored. For instance, in Ref. [6], the study was limited to shear strength reduction due to crude oil. In a study carried out by Daniel-Kalia and Pepples [7] on the Effects of Bony Light Crude Oil Pollution on soils, the interest was only on plant growth. Wokocha et al. [8] in their study on the impact of crude oil spillage on soils, the emphasis was on food production while Amadi et al. [9] concentrated on microbiological properties of the soil in their study on the Chronic Effect of oil spill on soil properties. According to Refs. [10-12], very few studies that deal with geotechnical properties of oil contaminated soil are available in literature. More studies are therefore very needful, hence this research. The study will provide a short cut to bearing capacity evaluation of oil contaminated soil for the study area using the regression model once the percentage contamination is determined.

2. Materials and Methods

2.1 Study Location.

The Niger Delta, located within the Atlantic Coast line of Southern Nigeria, stretching up to 450 km and terminating at Imo-river entrance, is the world’s second largest delta [13]. It lies approximately on latitude $4^{o}3'$ to $4^{o}50'$ N and longitude $7^{o}5'$ to $7^{o}35'$ E, [14]. Within this region, there are no less than 606 oil fields with 355 on shore and 251 offshore with 5,284 drilled oil wells and 7,000 km of oil and gas pipelines [15, 16].

Mgbede in Ogba/Egbema/Ndoni Local Government Area, which shall constitute the study location, hosts several oil wells in which diverse oil activities are carried out on a daily basis. Ogba/Egbema/Ndoni Local Government Area is made up of three major ethnic groups, the Ogbas who inhabit the Ogba axis, the Egbemas at the Egbema axis and the Ndonis within the Ndoni area, each having its own traditional ruler [17]. Mgbede is a semi urban oil-bearing community within the Egbema axis of the local government area. It has a population of 9,000 people [18] made up of mainly farmers, artisans and workers in the companies engaged in oil exploration and exploitation activities [19]. The study area generally displays the same kind of geological formation of the delta areas. It lies within the fresh water alluvial zone and the Sombrero-Warri Deltaic plain of the Niger Delta, underlain by the coastal plain sand of the Benin geologic formation [20]. The soil in this area is generally a mixture of clay and silt with underlying coarse sand fractions.

2.2 Experimental Materials and Design

Soil samples were collected from the study area and analyzed for the load bearing properties. Four borehole samples of uncontaminated soil were collected, properly labeled and sent in polythene bags to the laboratory for the relevant load bearing analyses which include cohesion, angle of internal friction (which are shear strength properties) and bulk density. By simulation, these samples were mixed with different doses of crude oil (the contaminant) at 5%, 10%, 15% and 20% contamination and tested for the same properties. The crude oil used was obtained from the Agip oil well at Mgbede. It is the Sweet Crude (Bonny Light) with viscosity 0.02611 poises at 40 ^{o}C and specific gravity 0.8227 g/cm^{3}.

With the hand auger, holes up to 1.5 m below ground level were bored and soil samples collected at that depth. The coordinates of the boreholes were BH1-604870N, 247133E, 20 m height; BH2-604882N, 247553E, 23 m height; BH3-604917N, 247198E, 23 m height; BH4-604829N, 247203E, 21 m height.

2.3 Hypothesis

H_o: the bearing capacity of crude oil contaminated soil does not differ significantly with varying percentage contamination.

SLR (simple linear regression) technique was used to test this hypothesis which sought to know whether the load bearing capacity of the contaminated soil is significantly related to varying percentage contamination.

3. Results and Discussions

The following data, presented in Table 1 were obtained from the analyzed borehole samples.

From the table, the highest bearing capacity values for both square and strip footings and for all the four borehole samples were recorded at 0% contamination while the lowest values were at 20% contamination.

Table 2 presented the summary of the mean values of the load bearing capacity of the soil samples. A consistent decrease in the bearing capacity values for

Table 1 Summary of traxial test.

BH N	Depth	Percentage oil (%)	Bulk density	Cohesion C (KN/m^2)	ϕ^o angle of internal friction	Bearing capacity	
						Square footing	Strip footing
	1.5	0	2.20	95	17	579.54	489.95
	1.5	5	2.15	85	15	423.77	357.84
1	1.5	10	2.24	40	7	174.11	148.53
	1.5	15	2.23	30	4	111.50	95.42
	1.5	20	2.23	25	3	95.42	82.02
	1.5	0	2.21	54	9	227.60	193.06
	1.5	5	2.21	40	4	143.52	122.09
2	1.5	10	2.21	20	6	97.04	84.26
	1.5	15	2.22	17	5	69.62	60.52
	1.5	20	2.20	14	3	59.84	52.34
	1.5	0	2.23	48	17	313.89	268.64
	1.5	5	2.14	40	14	214.12	183.12
3	1.5	10	2.21	37	13	201.06	172.38
	1.5	15	2.18	24	9	112.12	96.78
	1.5	20	2.09	13	5	55.88	48.92
	1.5	0	2.16	89	31	1,208.80	1,029.78
	1.5	5	2.11	80	28	814.97	693.20
4	1.5	10	2.19	40	12	214.77	183.76
	1.5	15	2.18	39	14	209.98	179.75
	1.5	20	2.14	33	11	181.53	155.96

Source: researcher's computation.

Table 2 Summary of mean bearing capacity values.

Serial No.	Percentage oil (%)	Bearing capacity (KN/m^2)	
		Square footing	Strip footing
1.	0	582.456	495.350
2.	5	240.735	204.753
3.	10	321.795	274.593
4.	15	127.003	109.12
5.	20	105.280	90.758

Source: researcher's computation.

both footing types was noticed as the percentage of crude oil increased.

This trend shows that increase in crude oil content reduces the shear strength parameters as the soil particles will more easily slip or shear with high oil content. The shear strength of the soil is a crucial property since it controls the bearing capacity as well as the stability of the foundation system of a civil engineering structure [21]. At 0% contamination, the bearing capacity values for square and strip footings yielded 582.458 KN/m^2 and 495.350 KN/m^2, respectively, and progressively decreased to 105.880 KN/m^2 and 90.758 KN/m^2 at 20% contamination respectively. Similarly, the values of cohesion (*c*) and angle of internal friction (θ) were found to be decreasing with increase in oil content as shown in Table 1. These are the shear strength parameters. While angle of internal friction refers to the friction between the soil particles, cohesion is a measure of the strength of the bond between these particles. The decrease in the shear strength, hence, the bearing capacity, is due to the reduction in the values of the cohesion and angle of internal friction. This finding is in line with earlier results obtained by Ref. [22]. The above relationship was further analyzed statistically using SLR (simple linear regression) technique to develop a regression model for the study location.

4. Hypothesis Testing

The hypothesis formulated earlier which sought to know whether there exists a strong relationship between the bearing capacity of oil contaminated soil and varying percentage contamination was tested using the SPSS (Statistical Package for Social Sciences) at 95% level of confidence. Data transformation tool from SPSS was used to obtain the square root values of all the dependent variables for the purpose of this regression. ANOVA (analysis of variance) table was used for further confirmation of the adequacy of the model.

4.1 Regression Model for Mgbede to Measure Percentage (%) Contamination against Bearing Capacity (Square Footing)

In Table 3, the *R* square value is 0.817, the ANOVA in Table 4 showed a significant *p*-value of 0.035.

The regression model for square footing denoted as MBC_{square} becomes:

$$MBC_{square} = 22.222 - 0.64 \times P \quad (1)$$

where, MBC_{square} = Mgbede bearing capacity for square footing.

P = Percentage contamination (%).

In Table 5, the standardized beta coefficient is -0.904 while the significant *p*-value = 0.035

4.2 Regression Model for Mgbede to Measure Percentage (5) Contamination against Bearing Capacity (Strip Footing).

In Table 6, for the strip footing the *R* square value is 0.814, the ANOVA in Table 7 shows a significant value of 0.036.

Table 3 Model summary for Mgbede (square footing).

Model	*R*	*R* square	Adjusted *R* square	Std. error of the estimate
1	0.904[a]	0.817[a]	0.756	2.766675

[a]Predictor: (constant) percentage (%).

Table 4 Analysis of variance.

Model	Sum of squares	*df*	Mean square	*F*	Significance
Regression	102.356	1	102.3756	13.372	0.035[a]
Residual	22.963	3	7.654		
Total	125.320	4			

[a]Predictor: (constant), percentage (%).

Table 5 Coefficients (dependent variable MBC_{square} footing).

Model	Un-standardized coefficient		Standardized coefficient Beta	t	Significance
	B	Std. Error			
(Constant) Percentage (%)	22.222 -0.640	2.143 0.175	 -0.904	10.369 - 3.657	0.0002 0.035

Table 6 Model summary for Mgbede.

Model	R	R square	Adjusted R square	Std. error of the estimate
(Constant) Percentage (%)	0.902[a]	0.814	0.752	2.556044

[a]Predictors: (constant), percentage (%).

Table 7 Analysis of variance (ANOVA).

Model	Sum of squares	df	Mean square	F	Significance
Regression	85.978	1	85.978	13.160	0.036[a]
Residual	19.600	3	6.533		
Total	105.578	4			

[a]Predictor: (constant), percentage (%)

Table 8 Table of coefficients.

Model	Unstandardized coefficient		Standardized coefficient Beta	t	Significance
	B	Std. Error			
(Constant) Percentage (%)	20.486 -0.586	1.980 0.162	 -0.902	10.347 -3.628	0.0002 0.036

[a]Dependent variable, MBC_{strip} footing.

The regression model for strip footing denoted as MBC_{strip} becomes:

$$MBC_{strip} = 20.586 - 0.586 \times P \quad (2)$$

where, MBC_{strip} = Mgbede bearing capacity for strip footing.

P = percentage contamination (%).

In Table 8, the standardized beta coefficient is -0.902 with a significant p-value of 0.036.

4.3. Decision Rule

The null hypothesis is accepted if the calculated p-value is greater than 0.05 ($p > 0.05$), otherwise it is rejected and the alternative, which is the research hypothesis is accepted.

The result of the only null hypothesis showed that the calculated p-values in all cases were less than 0.05 ($p < 0.05$). The research hypothesis is therefore accepted while the null is rejected. This therefore suggests that there is a strong and significant relationship between the load bearing capacity of crude oil contaminated soil and the degree of contamination. This is consistent with earlier works in literature. Evgin and Das [23] in their findings suggested that settlement of foundation footing would increase as a result of oil contamination. Also the findings of Shin and Das [24] indicated that the load bearing capacity of the soil drops with increase in oil content.

5. Conclusions and Recommendations

Crude oil pollution reduces the values of cohesion, angle of internal friction and consequently the bearing capacity of the contaminated soil. The study also revealed that as the crude oil content increases there is a decrease in the strength parameters of the soil establishing a correlation between the soil's bearing capacity value of crude oil contaminated soil and the percentage contamination. The researcher therefore recommends that the design of any structure that depends on soil for strength and stability in sites prone to crude oil pollution must consider the reduction factors generated by the pollutants to ensure that the soil could still function as a reliable structural support for the intended load. More studies are however required to test whether the reduction in bearing capacity values of oil contaminated soils is statistically significant.

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