Statistical Significance of Reduction in Load Bearing Properties of Crude Oil Contaminated Soil in Kwale, Niger Delta

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Abstract: The Niger Delta has experienced tons of crude oil spill within their environment over the years and its impact on the environment is quite lethal. The soil is a major recipient of this spilled crude. When contaminated with crude oil, the load bearing capacity is consequently affected. This study aimed at providing a statistical evidence to prove that the impact of crude oil contamination on the soil's bearing capacity is significant. Four samples of uncontaminated soil of Kwale were collected and analyzed for their load bearing properties: cohesion (c), angle of internal friction (θ°) and bulk density (γ). These soil samples were polluted with crude oil in levels of 5%, 10%, 15% and 20% and compared with intact soil. A consistent reduction was observed in the bearing capacity as the crude oil level increased. Using the SPSS (statistically package for social sciences), the significance was tested at the various contamination levels at a 5% confidence level and the result showed significance at 15% and 20% levels with calculated P -values of 0.038 and 0.035 respectively for both the square and strip foundation footings.

Key words: Bearing capacity, soil, contamination, crude oil, environment.

1. Introduction

The frequency of oil spill has been on a steady increase in most of the oil producing communities in the Niger Delta region of Nigeria. The impact is lethal and multidimensional. The soil bearing capacity which is the ability of the soil to support structure load is the first to receive the brunt of this phenomenon when it occurs. Crude oil, when spilled, moves both vertically, by gravity and horizontally, as it flows and spreads throughout the length and depth of the receiving soil, destroying the vegetal, terrestrial and aquatic environments. According to Pamukcu and Hijazi [1] the spillage of hydrocarbon liquid moves downward under gravity partially saturating the soil in its path towards groundwater level. Generally hydrocarbon is more viscous than water, therefore it relatively moves slower within the groundwater body Zulfahmi et al. [2].

Several studies investigating the effects of hydrocarbon on the engineering properties of the soil have been carried out. Evgin and Das [3], using triaxial tests examined the effects of crude oil on contaminated clean sands, and Shin and Das [4] also studied the effect of crude oil on load bearing capacity of sand at oil contents ranging from 0% to 6%. Khamsehchiyan et al. [5] investigated the effects of crude oil contamination on geotechnical properties of clayey and sandy soils. Aiban [6] examined the effects of temperature on engineering properties of oil contaminated sand in Kuwait, while Oku [7] studied the spatial variation of soil properties on oil spillage sites in the Niger Delta, Nigeria. All these studies agreed on the reduction of soil strength due to crude oil, but none explored whether this reduction in soil strength is statistically significant.

This study, therefore, aimed at investigating the statistical significance of the reduction in the load bearing properties of the Kwale soil due to crude oil

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contamination.

2. Material and Methods

2.1 Study Location

Kwale is one of the major towns in Ndokwa West LGA (Local Government Area) of Delta State and the headquarters of the LGA, Ndokwa West. A large expanse of the land has been used up by the oil field with several oil wells. This made the neighboring communities highly vulnerable to spills. The area experiences double rainfall peaks in June/July and September/October, with an average temperature of 30 °C [8]. The heavy precipitation assists in the downward movement of oil to the ground water table.

2.2 Experimental Procedure and Design

To generate the data set for this study, four soil samples were collected from four boreholes in the study area and analyzed through appropriate laboratory tests. These samples were collected using the hand auger. Triaxial tests were conducted on the remolded

soil samples before and after contamination. The bulk density, height, diameter and initial moisture content of the specimen were determined. The specimen was then enclosed with rubber membrane and mounted on the base of the triaxial cell with solid end caps placed on either ends. With the triaxial cell placed in the compression machine, hydrostatic pressure as required was applied and kept constant till the end of the experiment. The test was repeated on two identical specimens with increasing pressure. Mohr circles were drawn for each test at failure and a common tangent drawn to the Mohr circles gave the failure envelope from where the parameters cohesion (c) and angle of internal friction (θ°) were determined. This was done for all the four borehole samples and the results presented in Table 1.

2.3 Hypothesis

The hypothesis adopted in this study, H_o is that the reduction due to crude oil spill on the bearing capacity of crude oil contaminated soil is not significant.

Table 1 Summary of triaxial test results.

Bore hole number	Depth	Percentage oil (%)	Bulk density (g/cm ³)	Cohesion (kN/m ²)	Angle of internal friction (θ°)	Bearing capacity (kN/m ²)	
						Square footing	Strip footing
1	1.5	0	2.07	84	32	1,154.97	975.95
	1.5	5	2.11	23	5	88.18	75.82
	1.5	10	2.10	14	3	59.23	51.74
	1.5	15	2.11	11	2	4,959.00	43.70
	1.5	20	2.10	10	2	46.30	40.95
2	1.5	0	2.09	57	20	362.24	308.50
	1.5	5	2.07	45	15	236.49	201.58
	1.5	10	2.11	33	10	146.04	124.94
	1.5	15	2.09	113	2	55.88	48.88
	1.5	20	2.10	8	2	39.87	35.59
3	1.5	0	2.10	76	27	777.70	662.40
	1.5	5	2.09	60	22	482.93	412.02
	1.5	10	2.10	24	8	111.39	96.05
	1.5	15	2.10	18	7	88.35	76.85
	1.5	20	2.10	18	6	88.35	76.85
4	1.5	0	2.08	68	23	539.50	459.11
	1.5	5	2.11	52	18	334.30	285.28
	1.5	10	2.11	38	13	204.55	174.96
	1.5	15	2.09	26	9	118.98	102.36
	1.5	20	2.10	23	8	107.55	92.85

The objective of this hypothesis was to determine whether the reduction observed in the bearing capacity of crude oil contaminated soil of Kwale, is statistically significant. To test this hypothesis, paired sample *t*-test was used and the results presented in Tables 2a and 2b.

The bearing capacity values for square and strip footings, for each borehole sample were calculated using Terzaghi's bearing capacity theory with the relevant bearing capacity factors as follows:

for square footing:

$$q_u = 1.3cN_c + \gamma D_f N_q + 0.4\gamma B N_\gamma \quad (3)$$

for strip footing:

$$q_u = cN_c + \gamma D_f N_q + 0.5B\gamma N_\gamma \quad (4)$$

where, N_c , N_q and N_γ are bearing capacity factors assumed by Terzaghi, and c is cohesion, D_f is foundation depth, B is foundation width, γ is bulk density

3. Results and Discussion

From Table 1 for borehole sample 1, at 0% contamination (control), the bearing capacities were 1,154.97 kN/m² and 975.95 kN/m² for square and strip footings respectively. At 5% contamination (observed) they dropped drastically to 88.18 kN/m² and 75.82 kN/m², respectively. The bearing capacity at 10%, 15% and 20% (observed) were recorded as 59.23 kN/m² and 51.74 kN/m², 49.59 kN/m² and 43.7 kN/m², and 46.30 kN/m² and 40.95 kN/m² for both square and strip footings, respectively. Similarly for the other three borehole samples the bearing capacity values were as recorded in Table 1.

Table 3 presented the summary of the mean values of the bearing capacity of Kwale soil at the various contamination levels. It was clearly evident that there was a consistent reduction in the values from 708.603 kN/m² and 601.49 kN/m² down to 70.518 kN/m² and 61.56 kN/m² at 0% and 20% contamination levels for the square and strip footings respectively. These results were used for the statistical analysis employing the SPSS (Statistically Package for Social Sciences).

From the statistics in Tables 2a (i-viii), the tests were

conducted on the paired mean values of the bearing capacity for square and strip footings at 0% and 5%, 0% and 10%, 0% and 15%, 0% and 20% for all the borehole samples. The paired sample statistics in Table 2a (i) showed the paired bearing capacity at 0% and 5%, whose mean values were 708.603 kN/m² and 285.475 kN/m². N in column three indicated the number of samples which is 4. The standard deviation and standard error were presented in columns 4 and 5. Table 2b (i) presented the actual statistical test of the paired samples. At 95% confidence interval the level of significance was 0.147 on a two tailed test. Also in Table 2a (ii), the bearing capacity at 0% was paired against that at 10% (708.603 kN/m² against 130.303 kN/m²). The result of the test showed a significance level of 0.061 shown in Table 2b (ii). In the same vein, in Tables 2a (iii-iv) and 2b (iii-iv), the results of the paired tests were 0.038 and 0.035 for 0%/15% and 0%/20% pairs. The results of the hypothesis showed a significance level of 0.038 and 0.035 at 15% and 20% contamination levels respectively indicating statistical significance. These results recorded in Tables 2a and 2b (i-iv) were for square footing.

The strip footing results were presented in Tables 2a and 2b (v-viii). Similar tests were conducted and the results showed that at 15% and 20% contamination levels the test of significance indicated 0.038 and 0.035 respectively while at 5% and 10% the levels of significance were 0.147 and 0.061, respectively.

About decision rule, the null hypothesis is accepted if the calculated value is greater than 0.05 ($P > 0.05$), otherwise it is rejected and the alternative, which is, the research hypothesis, H_1 is accepted. The result of the only null hypothesis showed that the calculated P -values at 5% and 10% contamination levels were more than 0.05 ($P < 0.05$). The null hypothesis was therefore accepted at that point while the alternative which is the research hypothesis was rejected. Furthermore at 15% and 20% contamination levels, the calculated P -values of 0.038 and 0.035 for both the square and strip footings respectively were

Tables 2 Paired sample t-test (a and b).

(a) Paired sample statistics square footing (i)						
Pairs	Mean	N (number of samples)	Standard deviation	Standard error mean		
Pair 1 BC _{square} 0%	708.6030	4	342.82213	171.41107		
Pair 1 BC _{square} 5%	285.4750	4	166.02932	83.01466		
Paired sample statistics square footing (ii)						
Pair 2 BC _{square} 0%	708.6030	4	342.82213	171.41107		
Pair 2 BC _{square} 10%	130.3025	4	61.01733	30.50866		
Paired sample statistics square footing (iii)						
Pair 3 BC _{square} 0%	708.6030	4	342.82213	171.41107		
Pair 3 BC _{square} 15%	78.2000	4	32.05592	16.02796		
Paired sample statistics square footing (iv)						
Pair 4 BC _{square} 0%	708.6030	4	342.82213	171.41107		
Pair 4 BC _{square} 20%	70.5175	4	32.73714	16.36857		
Paired sample statistics strip footing (v)						
Pairs	Mean	N	Standard deviation	Standard error mean		
Pair 1 BC _{square} 0%	601.4900	4	288.70142	144.35071		
Pair 1 BC _{square} 5%	243.6750	4	141.44293	70.72146		
Paired sample statistics strip footing (vi)						
Pair 2 BC _{square} 0%	601.4900	4	288.70142	144.35071		
Pair 2 BC _{square} 10%	111.9225	4	51.69478	25.84739		
Paired sample statistics strip footing (vii)						
Pair 3 BC _{square} 0%	601.4900	4	288.70142	144.35071		
Pair 3 BC _{square} 15%	67.9475	4	27.17220	13.58610		
Paired sample statistics strip footing (viii)						
Pair 4 BC _{square} 0%	601.4900	4	288.70142	144.35071		
Pair 4 BC _{square} 20%	61.5600	4	27.76125	13.88063		

(b) paired samples test (i) square footing							
	Paired differences						
	Mean	Std. deviation	Std. error mean	95% confidence interval of the difference		t	df
				Lower	Upper		Significance (2-tailed)
Pair 1	423.12750	434.62736	217.31368	-268.46162	1,114.71662	1.947	3
Paired Samples Test (ii)							
	Paired differences						
	Mean	Std. deviation	Std. error mean	95% confidence interval of the difference		t	df
				Lower	Upper		Significance (2-tailed)
Pair 2	578.30000	394.04972	197.02486	-48.72104	1,205.32104	2.935	3
Paired samples test (iii)							
	Paired differences						
	Mean	Std. deviation	Std. error mean	95% confidence interval of the difference		t	df
				Lower	Upper		Significance (2-tailed)
Pair 3	630.40250	355.02706	177.51353	65.47522	1,195.32978	3.551	3
Paired Samples Test (iv)							
	Paired differences						
	Mean	Std. deviation	Std. error mean	95% confidence interval of the difference		t	df
				Lower	Upper		Significance (2-tailed)
Pair 4	638.08500	349.40232	174.70116	82.10794	1,194.06206	3.652	3

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(b) Paired samples test (v) strip footing								
	Paired differences					<i>t</i>	df	Significance (2-tailed)
	Mean	Std. deviation	Std. error mean	95% confidence interval of the difference				
				Lower	Upper			
Pair 1	357.81500	366.26339	183.13170	-224.99179	940.62179	1.947	3	0.146
Paired Samples Test (vi)								
	Paired differences					<i>t</i>	df	Significance (2-tailed)
	Mean	Std. deviation	Std. error mean	95% confidence interval of the difference				
				Lower	Upper			
Pair 2	489.56750	331.98725	165.99362	-38.69829	1,017.83329	2.949	3	0.060
Paired samples test (vii)								
	Paired differences					<i>t</i>	df	Significance (2-tailed)
	Mean	Std. deviation	Std. error mean	95% confidence interval of the difference				
				Lower	Upper			
Pair 3	533.54250	298.86540	149.43270	57.98096	1,009.10404	3.570	3	0.038
Paired samples test (viii)								
	Paired differences					<i>t</i>	df	Significance (2-tailed)
	Mean	Std. deviation	Std. error mean	95% confidence interval of the difference				
				Lower	Upper			
Pair 4	539.93000	294.17820	147.08910	71.82684	1,008.03316	3.671	3	0.035

Table 3 Mean bearing capacity values.

S/N	Percentage of oil contamination	Bearing capacity (kN/m ²)	
		Square footing	Strip footing
1	0	708.603	601.490
2	5	285.475	243.683
3	10	130.303	111.923
4	15	78.200	67.948
5	20	70.518	61.560

less than 0.05 ($P < 0.05$), the null hypothesis was rejected while the research hypothesis was accepted. This suggests therefore that at higher crude oil pollution levels the impact is significantly high. This finding is consistent with the findings of Shin and Das [8] which indicated that the load bearing capacity of the soil drops significantly with increase in crude oil content.

4. Conclusion and Recommendations

From the study, it became evident that statistically speaking, the impact of crude oil spill on the soil is significant to cause appreciable damage to the soils load bearing properties in Kwale, an oil producing community, at beyond 10% contamination. It therefore becomes imperative for the oil operators to apply every

reasonable means to drastically reduce if not completely eliminate spillage in the environment especially within the host communities. Furthermore, deliberate policies and enabling laws ought to be enacted to specifically address spillage issues, and implementation pursued vigorously to mitigate impacts.

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