Effect Of Hydrocarbon Content On Geotechnical And Chemical Properties On Uyo Coastal Plain Sands, Akwa Ibom State Eastern Nigeria

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***Abstract*— This study was carried out to analyze the effect of hydrocarbon contaminated soils on foundation taking Uyo mechanic village as a case study. To achieve the aim, soil samples were collected from four selected areas within the mechanic village and one sample outside this area to act as a control. Geotechnical tests carried out included the natural moisture content, specific gravity, Atterberg limits, compactions, particle size distribution, consolidation, unconfined compression test and direct shear test. In addition, chemical tests were also carried out to determine the total petroleum hydrocarbon (TPH), pH, sulphate and chloride content on the collected samples. Results showed that the specific gravity were not adversely affected by the effect of hydrocarbon contamination. All sampled soils classified according to Unified Soil Classification System (USCS) indicated that the soils were inorganic soils of low compressibility. The maximum dry density of all samples fell within the range of 1.77 Mg/m^3 and 1.84 Mg/m^3. The compression index values fell between 0.094 and 0.195 and the coefficient of consolidation fell between 1.06 m^2/yr and 1.25 m^2/yr. In carrying out the shear strength test, the value of the unconfined compressive strength ranged between 20.65 kN/m^3 and 174.02 kN/m^3 and indicated a consistency that fell between very soft to medium. The cohesion fell between 10.48 kN/m^2 and 25.9 kN/m^2 while the angle of internal friction fell between 13^0 and 18^0. An increase was observed in the values of compression index and cohesion with an increase in the hydrocarbon content. An increase in the total petroleum hydrocarbon content led to a decrease in the optimum moisture content, plasticity index, shrinkage limit, angle of internal friction and the bearing capacity. In conclusion, remediation which involves removing the contaminated soils should be carried out on the area before foundations are placed.**

Keywords—Oil contaminated soil, Geotechnical properties, bearing capacity, Mechanic workshop

I. INTRODUCTION

Soil contamination is caused by alterations in the natural soil environment. It is typically caused by industrial activity or by improper disposal of waste. The most common chemical involved are petroleum hydrocarbon, polycyclic aromatic hydrocarbon pesticide, lead and other heavy metals. This dissertation focuses on the effect of petroleum hydrocarbon contamination as it affects the geotechnical properties of soils in the coastal plain sands, using the mechanic village, Uyo, of Akwa Ibom State as a case example.

Hydrocarbon contamination does not just affect the ecosystem, but also the safety of civil engineering structures on a long run [1]. The cleaning up of these soils is a complicated job by virtue of high cost and limitations in disposing the excavated soils [1]. The spillage of such hydrocarbon liquids on a long run moves downward under gravity, partially saturating the soil in its pathway towards ground water level [2]. Saturation of soils by hydrocarbon liquids are expected to change the engineering behavior of soils. The fabric and the mineralogy are among factors that controls the mechanic properties besides stress history and initial density [3]. Generally, hydrocarbon is more viscous than water, therefore it is relatively slower within ground water bodies. Some are trapped and clogged, reducing pore volume leading to a reduction in hydraulic conductivity of contaminated soils [4].

Contamination of soils by petroleum hydrocarbon is very common in areas in the vicinity of motor mechanic workshops. It has been reported that the engineering properties of such soils are drastically changed and made unsuitable for supporting engineering structures. At the sites with excessive oil contaminations, vertical settlement is usually expected to occur. These do not only occur on highways, but in garages, petrol stations and oil storage sites are common sites contaminated with such contaminations. The extent of contamination has a lot to do with the chemical composition of contaminants and properties of the soil [1].

The increasing number of vehicles in Nigeria has necessitated the high production of hydrocarbon. This has subsequently given rise to the generation of large quantities of petroleum hydrocarbon waste at the time of servicing vehicles [5]. These materials are considered as ordinary waste by majority of workers in automobile workshops who dispose these fluids by dumping on surface soils.

II. Material and Methods

The area consists mainly of mechanic workers which constitute about a larger percentage of the total work force that includes panel beaters, welders, automobile electrician, painters, automobile upholstery workers, automobile spare parts dealers, vulcanizers and black smiths. The level of Education of these workers partly explains the difficulty of controlling the method of disposal of hydrocarbon materials in the Area. The Uyo Mechanic village has its co-ordinates as Latitude $4^0 32^I$N and 5^0 33^IN and longitude $7^0 25^I$E and $8^0 25^I$E.

The geological formation in Uyo is the Coastal Plain Sands, which occupies more than 75% of Akwa Ibom State. The local geology of the project area is that of the generalized Pleistocene- Oligocene coastal plain sands. The major geologic materials include gravel, sand, silt, clay and alluvium [6].

Samples were obtained from five different points within the study area and their coordinates were gotten using a google locator and tabulated in Table 1.

Disturbed samples were obtained from hand dug trial pit up to a dept of 1.5m. All sample were identified serially, encased in polyethylene plastic wrappings to protect against moisture loss, and transported to their respective Laboratory in special containers for both chemical and geotechnical tests.

The following laboratory tests carried out on selected samples recovered from the study location were grouped into two.

III. Material and Methods

These tests were carried out using standard testing procedure and they are sub divided into the following

A. *Natural Moisture Content*

The natural moisture content of the soil under investigation was determined following ASTM D2216. A test specimen is dried in an oven at a temperature of about 105^0C ± 5^0C to a constant mass. The loss of mass due to drying is considered to be water. The water content is calculated using the mass of water and the mass of the dry specimen.

B. *Specific Gravity*

A pycnometer bottle was used in determining the specific gravity in accordance to ASTM D854-98. The specific gravity of solid is a measure of and a means of expressing the heaviness of the material

C. *Consistency of the Soil Sample*

To determine the consistency of the soils at the study location, their Atterberg limits which comprises of the liquid limit, plastic limits and plasticity indices were determined. The liquid limit and plastic limit were determined in accordance to ASTM D423 and ASTM D424. The plasticity of the material is the arithmetic difference between the already determined Liquid limit and plastic limit.

D. *Grain Size Analysis*

The size of soil particle and their distribution throughout the soil mass are important factors which influences soil properties and performance.

E. *Standard Compaction Test*

Compaction tests are generally done to improve the engineering properties of soil. Compaction generally increases the shear strength of the soil and hence the stability and bearing capacity. The ASTM D1557 for the modified proctor test is applied in the compaction experiment. The soil was compacted in the proctor mold using 25 blows from a 4.5kg hammer falling from a distance of 0.457m on each of 5 equal layers. The optimum moisture content and the maximum dry density were found by series of determinations of dry unit weight and the corresponding moisture content.

F. *Consolidation Test*

This test was based on ASTM D2435. These test methods cover procedures for determining the magnitude and rate of consolidation of soil when it is restrained laterally and drained axially while subjected to incrementally applied controlled-stress loading. The soil sample in an oedometer test typically has a diameter to height ratio of 3. The sample held in a rigid ring prevents lateral displacement of the soil sample but allows for the sample to swell or compress vertically in response to changes in the applied load. Vertical stresses are applied to the top and bottom faces of the sample using free weights and a lever arm. The changes in the thickness of the sample are thereafter measured.

G. Unconfined Compression Test

This test was carried out in accordance to ASTM D2166. It is assumed that no pore water is lost from the sample during set-up or during the shearing process. The saturated sample remained saturated during the test with no change in the sample volume, water content or void ratio. The sample is held together by an effective confining stress that results from negative pore water pressures. Pore pressures are not measured in an unconfined compression test; consequently, the effective stress is unknown. Hence, the undrained shear strength measured in an unconfined test is expressed in terms of the total stress.

H. Direct Shear Test

Shear strength of a soil is defined is the maximum resistance to shearing stress. The angle of internal friction and cohesion of the soil were determined using a direct shear box

IV. Chemical Test

The chemical tests that were carried out includes the pH test, sulphate, chloride and Total Petroleum Hydrocarbon.

A. pH

The concept of pH is unique among the commonly encountered physicochemical quantities listed in the International Union of Pure and Applied Chemistry (IUPAC) Green Book. In terms of its definition, it involves a single ion quantity, the activity of the hydrogen ion, which is immeasurable by any thermodynamically valid method and requires a convention for its evaluation. A pH meter was used to read off the pH value. The method adopted for this test was ASTM D4972-19.

B. Sulphate

This test method was used to determine if soils could have an adverse reaction with concrete. The designated standard used in carrying this out was ASTM C1580 – 15.

C. Chloride

Chloride attack is one of the most important aspect while dealing with durability of concrete foundation. It primarily causes corrosion of reinforcement. In foundation, if the concrete is permeable to such an extent that soluble chlorides penetrate right up to the reinforcement and water and oxygen is also present, then the corrosion of steel will take place. The ASTM standard test used in determining the chloride content is ASTM D512-12.

D. Total Petroleum Hydrocarbon

Total petroleum hydrocarbons (TPH) are the term generally used to describe the amount of petroleum-based hydrocarbon extracted and quantified by a particular method in an environment. Total petroleum hydrocarbon of the soil sample was determined by the method of Intergovernmental Oceanographic Commission (IOC). 100 grams of the soil samples were refluxed with 100 mL of methanol containing about 3.0g of KOH for 2.5h. The refluxed mixture was filtered and the filtrate was extracted with two 2.5 mL portion of redistilled hexane. The combined extracts were evaporated to about 1.0 mL and then subjected to clean up in a silica column, eluted with n-hexane. The eluate was subsequently evaporated to isolate the hydrocarbon oil which was then weighed.

V. Results and Discussion

The results of the geotechnical and chemical properties of the contaminated and uncontaminated petroleum hydrocarbon soils for the five locations are shown in Tables 2, 3 and 4.

TABLE 1 COORDINATES OF SAMPLE LOCATIONS

Sample No	Depth(m)	Location	Coordinates	Nature of Sample
1	<1.0	Ekpot Ossom (Afaha Offot)	Lat 05^0 01’ 51.58’’N Long 07^0 53’40.28’’E	Control
2	<1.0	Mount Zion Lighthouse Full Gospel church, Mechanic Village (Signboard)	Lat 05^0 01’ 40.23’’N Long 07^0 53’51.75’’E	Contaminated soil
3	<1.0	Opposite Akwa United Football Club house	Lat 05^0 01’ 37.32’’N Long 07^0 53’56.95’’E	Contaminated soil
4	<1.0	Inside Mechanic Village (Blue Lotto)	Lat 05^0 01’ 34.81’’N Long 07^0 53’ 59.98’’E	Contaminated soil
5	<1.0	Mechanic Village Hall	Lat 05^0 01’ 39.30’’N Long 07^0 54’ 00.39’’E	Contaminated soil

TABLE 2 INDEX PROPERTY OF TESTED SOIL SAMPLES AND USCS

Sample code	SG	NMC	LL	PL	PI	SL	Grain Size			Classification
		%	%	%	%	%	Gravel %	Sand %	Silt & clay %	USCS
2	2.61	12.75	40.2	28	12	21	0	78.47	21.53	Inorganic Silt of low compressibility
3	2.60	15.06	40.9	29.3	12	17	0	82.31	17.69	Inorganic Silt of low compressibility
4	2.66	5.88	-	-	-	-	0	92.98	7.02	No Plasticity
5	2.65	13.04	40	27.5	13	21.8	0	78.18	21.82	Inorganic Silt of low compressibility
Control	2.58	21.47	44	29.3	15	29	0	70.45	29.55	Inorganic Silt of low compressibility

TABLE 3 COMPACTION, CONSOLIDATION AND SHEAR STRENGTH PROPERTIES

Sample code	MDD	OMC	Mv (m^2/MN)		Cv (m^2/yr)		Cc	USS	UCS	∅	c	Bearing Capacity
	Mg/m^3	%	min	max	min	max		kN/m^2	kN/m^2	^{0}	kN/m^2	kN/m^2
2	1.78	11.6	0.38	0.09	1.07	1.25	0.20	33.95	67.91	13	25.90	168.48
3	1.84	12.9	0.23	0.1	0.87	1.06	0.19	42.11	84.21	18	12.46	158.78
4	1.77	10.1	0.28	0.06	0.97	1.22	0.09	10.33	20.65	-	-	-
5	1.79	13.7	0.17	0.26	0.98	1.17	0.14	87.01	174.02	18	10.48	141.10
Control	1.79	15.4	0.32	0.11	0.87	1.13	0.19	26.62	53.23	16	21.00	183.98

TABLE 4PH, SULPHATE, CHLORIDE AND TPH VALUES.

Sample code	pH in H_{2-}O	SO_4^{2-} (mg/Kg)	Cl (mg/Kg)	TPH (mg/Kg)
2	5.86	9.80	21.40	1.08
3	6.66	6.60	12.48	0.84
4	7.22	7.14	10.40	0.61
5	5.29	8.88	14.40	0.44
Control	7.45	14.70	20.00	0.48

Natural moisture content of soil of the study area from Table 2 ranges from 5.88 – 15.06% for the contaminated soils and 21.47% for the control sample indicating a decrease in Natural Moisture content due to contamination. The moisture content does not show the property of a soil alone but might give a little insight on the nature of the soil. Soils that are freely drained have low moisture content and could be classified as sand with minor or no clay content.

The specific gravity data from Table 2 shows lower value (2.578) for control soil samples relative to contaminated samples (2.599 – 2.654) suggesting an increase due to oil contamination. The Specific gravity gives an idea about the suitability of a soil as a construction material; higher value of specific gravity gives more strength for roads and foundations [7]. An increase in specific gravity can increase the shear strength parameters (cohesion and angle of shearing resistance) [8].

Table 2 show higher Liquid Limit and Plasticity Index values for control samples compared to oil contaminated samples. This indicates that oil content results in decrease in Liquid limit and Plasticity Index.

The results of grain size distribution are shown in Fig 1 and Table 2. Sand varied from 78.18 to 9.98% for contaminated sand and 70.45% non-contaminated sand. The fines (silt and clay) for non-contaminated sand are 29.55%, while it varies between 7.02 and 21.82% for contaminated sand.

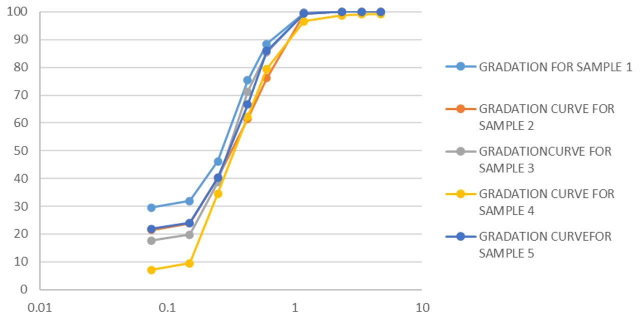

Fig. 1. *Particle size distribution of samples 1 to 5 on a semi log graph*.

From the maximum dry density (MDD) of Table 3, Uyo Mechanic village for the contaminated soil ranges from 1.77 kg/m^3 to 1.84 kg/m^3 and the optimum moisture content ranges 10.1 to 13.7%. For the control soil sample, the MDD and OMC is 1.79 kg/m^3 and 15.4% respectively.

According to USCS classification scheme most of the soil of the study area are silt of low compressibility. From the plot of plasticity chart shown in Figure 2, the soils found in uyo mechanic village are inorganic silts.

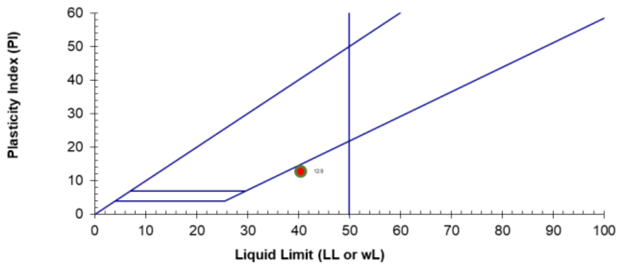

Fig. 2. *Plasticity chart for studied soils according to Unified Soil Classification System.*

The value of the coefficient of compressibility from Table 3 for the contaminated soil under minimum applied load ranges between 0.17 and 0.38 m^2/MN while that of the non-contaminated soil is 0.32 m^2/MN. Under the maximum applied load, the coefficient of compressibility for the contaminated soil varied between 0.06 and 0.26 m^2/MN while for the non-contaminated sample was 0.11 m^2/MN.

The consolidation coefficient for the control sample under minimum loading is 0.87 m^2/yr while for the contaminated samples showed an increase in its value and varies between 0.87 m^2/yr and 1.07 m^2/yr. Under maximum loading, the values increased. The Cv for contaminated sample varied between 1.06 and 1.25 m^2/yr while the non-contaminated sample had a Cv of 1.13 m^2/yr. The compression index data shows a value of 0.19 for the control soil sample while the contaminated samples fell in range between 0.09 and 0.20.

From the unconfined compressive strength on Table 3, the contaminated samples range between 20.65 and 174.02 kN/m^2 while the non-contaminated sample is 53.23 kN/m^2. The value of the undrained shear strength of the contaminated sample varies between 10.33 kN/m^2 and 87.01 kN/m^2 while the non-contaminated sample is 26.62 kN/m^2. The percentage passing through the 0.075mm sieve for the control sample is approximately 30% whereas the contaminated samples recorded lesser values of approximately 21%, 17%, 7% and 21%. This contributes to the differences observed in the unconfined compressive strength results.

The angle of internal friction of the control sample is 16^0 while the contaminated samples range between 13^0 and 18^0. The cohesion of the uncontaminated samples was found to be 21 kN/m^2 while the contaminated samples were found to be between 10.48 kN/m^2 and 25.9 kN/m^2.

The allowable bearing capacity of the uncontaminated soil sample is 183.98 kN/m^2 which is higher than the contaminated bearing capacities which ranges between 141.10 and 168.48 kN/m^2. This shows that a decrease is observed in the allowable bearing capacity with increasing total hydrocarbon content.

From Table 4, the pH of the contaminated soils is mainly acidic while control is alkaline (7.45). The SO_4^{2-} for the control soil is 14.70 mg/Kg while the contaminated soils showed a decrease in the contamination of SO_4^{2-} and ranges between 6.60 and 9.80 mg/Kg. The chloride constituent of the contaminated soils ranges between 10.40 mg/Kg and 21.40 mg/Kg as compared to the non-contaminated soil sample having a chloride constituent of 20.00 mg/kg. Certain measures help to control Chloride and sulphate attack. The quality of concrete, specifically of low permeability is the best protection against these attacks. These qualities of concrete include: inadequate concrete thickness, high cement content, low water-cement ratio and proper compaction and curing [9].

The TPH of the contaminated soil samples varied between 0.44 and 1.08 mg/Kg while control soil was 0.48 mg/Kg as can be seen in Table 4.3. This suggests higher values for the oil contaminated samples.

VI. Correlation between Geotechnical and Chemical Parameters

Correlation analysis is a method of statistical evaluation used to study the strength of a relationship between two numerically measured, continuous variables. Correlations are useful because they can indicate a predictive relationship that can be exploited in practice. Table 5 shows the correlations between the geotechnical and chemical parameters of the studied soils.

TABLE 5CORRELATION MATRIX BETWEEN THE GEOTECHNICAL AND CHEMICAL PROPERTIES OF TESTED SOIL

	SG	NMC	LL	PL	PI	SI	sand	silt&clay	MDD	OMC	Mv(min)	Mv(max)	Cv(min)	Cv(max)	Cc	USS	UCS	C	phi	BC	pH	sulphate	Cl	TPH
SG	1.00																							
NMC	-0.87	1.00																						
LL	-0.77	0.99	1.00																					
PL	-0.89	0.74	0.68	1.00																				
PI	-0.51	0.87	0.91	0.33	1.00																			
SI	-0.38	0.78	0.83	0.17	0.99	1.00																		
sand	0.73	-0.93	-0.86	-0.21	-0.99	-1.00	1.00																	
silt&clay	-0.73	0.93	0.86	0.21	0.99	1.00	-1.00	1.00																
MDD	-0.46	0.39	-0.11	0.59	-0.48	-0.61	-0.16	0.16	1.00															
OMC	-0.64	0.93	0.81	0.41	0.82	0.77	-0.89	0.89	0.33	1.00														
Mv(min)	-0.45	0.12	0.34	0.20	0.32	0.33	-0.17	0.17	-0.39	-0.19	1.00													
Mv(max)	0.27	0.17	-0.36	-0.68	-0.09	0.01	-0.37	0.37	0.05	0.47	-0.70	1.00												
Cv(min)	0.46	-0.54	-0.61	-0.82	-0.34	-0.20	0.22	-0.22	-0.62	-0.57	0.35	0.07	1.00											
Cv(max)	0.49	-0.55	-0.29	-0.72	0.03	0.17	0.27	-0.27	-0.89	-0.57	0.49	-0.12	0.89	1.00										
Cc	-0.90	0.77	0.38	0.66	0.12	0.03	-0.74	0.74	0.50	0.54	0.41	-0.09	-0.16	-0.36	1.00									
USS	0.20	0.16	-0.60	-0.72	-0.37	-0.28	-0.35	0.35	0.24	0.41	-0.69	0.96	0.10	-0.19	0.06	1.00								
UCS	0.20	0.16	-0.60	-0.72	-0.38	-0.29	-0.34	0.34	0.24	0.40	-0.69	0.96	0.11	-0.19	0.06	1.00	1.00							
C	-0.54	0.22	0.34	0.09	0.39	0.41	-0.44	0.44	-0.57	-0.20	0.99	-0.67	0.42	0.62	0.71	-0.75	-0.75	1.00						
phi	0.29	0.08	-0.05	0.17	-0.15	-0.21	0.23	-0.23	0.63	0.44	-0.93	0.54	-0.67	-0.79	-0.59	0.57	0.56	-0.95	1.00					
BC	0.19	0.17	-0.60	-0.72	-0.38	-0.28	-0.36	0.36	0.25	0.42	-0.68	0.96	0.10	-0.20	0.07	1.00	1.00	-0.75	0.57	1.00				
pH	-0.34	0.17	0.88	0.94	0.62	0.49	0.13	-0.13	0.00	0.03	0.34	-0.72	-0.61	-0.26	-0.06	-0.83	-0.83	0.29	0.00	-0.83	1.00			
sulphate	-0.61	0.77	0.86	0.24	0.98	0.98	-0.81	0.81	-0.29	0.72	0.43	0.05	-0.20	0.02	0.43	-0.10	-0.11	0.55	-0.35	-0.10	0.28	1.00		
Cl	-0.64	0.62	0.40	-0.07	0.56	0.62	-0.79	0.79	-0.22	0.45	0.68	-0.01	0.28	0.26	0.73	0.00	-0.01	0.95	-0.90	0.00	-0.13	0.76	1.00	
TPH	-0.25	-0.17	-0.43	0.01	-0.56	-0.56	0.13	-0.13	0.18	-0.47	0.58	-0.51	0.47	0.24	0.49	-0.28	-0.28	0.52	-0.64	-0.27	-0.18	-0.31	0.31	1.00

A. Correlation Relationship between TPH and Plasticity Index and Shrinkage Limit

From Table 5, the relationship between the TPH and the plasticity index is a significant negative correlation (-0.74). As the total petroleum hydrocarbon content increases, the plasticity index decreases and as the TPH increases, the shrinkage limit decreases. A similar result was also observed in crude oil contaminated coastal plain soils [4].

B. Correlation Relationship between TPH and Optimum Moisture Content

References to Table 5 indicates a -0.47 for correlation between the TPH and OMC. As the TPH increases, the OMC decreases. This same similarity was also observed in other studies [4][10][11][12].

C. Correlation Relationship between TPH and Compression Index

From Table 5, the relationship between the TPH and the compression index is +0.49 which indicates that the compression index increases with the increase in total petroleum hydrocarbon content. Other Research works observed a similar case with compression index [13].

D. Correlation between TPH and Cohession and Angle of Internal Friction

With respect to Table 5, the correlation value of the cohesion and angle of internal friction are 0.52 and -0.64 respectively. This As indicates that cohesion increased with increase in total petroleum hydrocarbon content and angle of internal friction decreased.

E. Correlation between TPH and Bearing Capacity

Table 5 indicates a correlation of -0.27 which simplifies to a decrease in bearing capacity with an increasing petroleum hydrocarbon contamination. Research works on the study of hydrocarbon showed that as hydrocarbon content increased, the bearing capacity decreased [14].

VII. CONCLUSSION

The following conclusions were made:

i. the TPH increases, an increase is observed for compressibility and consolidation coefficients under applied minimum pressure. A decrease is observed in compressibility coefficient under applied pressure at a maximum.

ii. As TPH increases the bearing capacity decreases.

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AUTHORS CONTRIBUTION

This research was carried out to enlighten and impact knowledge on the effect of hydrocarbon contaminated soils in coastal plain sands, making reference to Uyo mechanic village as a case study.

REFERENCES

[1] A. V. Shroff, D. L. Shah and S. J. Shah, “Stabilization of fuel oil contaminated soils,” American Journal of Applied Sciences, vol. 8(1), pp. 49 – 51, 2003.

[2] S. Pamuku and H. Hijazi, Grouting/soil Improvement and Geosynthetics, Geotechnical Special Publication, New York. 1992, 345p.

[3] R. P. Brenner, V. K. Garga and G. E. Blight, “Shear strength behavior and the measurement of shear strength in residual soils,” In Mechanics of residual soils, G. E. Blight and E. C. Leong, Eds. South Africa: Witwatersrand University, 1997, pp213 – 280.

[4] M. Khamehchiyan, A. Charkhabi, and M. Tajik, “Effects of crude oil contamination on Geotechnical properties of clayey and sandy soils,” Geotechnical properties of clayey and sandy soils. Journal of Geotechnical Engineering vol.17, pp 220-229, 2007.

[5] G. Solly, E. A. Aswathy, B. Sabu, N. P. Krishnaprabha and M. George, “Study on Geotechnical properties of diesel oil contaminated soil,” International Journal of Civil Civil and Structural Engineering Research, vol. 2, pp 113 – 117, 2015.

[6] U. I. Uchendu and P. A. Ogwo, “The effect of spent engine oil discharge on soil properties in an automobile mechanic village in Nekede, Imo State, Nigeria,” International Organisation of Scientific Research Journal of Environmental Science, Toxicology and Food Technology, vol.8, pp28 – 32, 2014.

[7] S. Roy, and S. Bhalla, "Role of Geotechnical properties of soil in Civil Engineering structures,"

International Journal of Natural Resources and Environment, vol. 7(4), pp 103 – 109, 2017.

[8] S. Roy, and G. Dass, “Statistical models for the prediction of shear strength parameters at Sirsa, India,” International Journal of Civil and Structural Engineering, Vol. 4(4), pp 483 – 498, 2014.

[9] J. Farny, and B. Kerkhoff, “*Diagnosis and control of alkali-aggregate reactions in concrete*,” Concrete Technology, Vol. 19(2), pp 1 – 26, 2007.

[10] Z. A. Rahman, U. Hamzah and N. Ahmad, “Geotechnical characteristics of oil- contaminated Granitic and Metasedimentary soils,” Asian Journal of Applied Sciences, Vol. 3 (4), pp 237 – 249, 2010.

[11] I. I. Akinwumi, U. R. Maiyaki, S. A. Adubi, S. O. Daramola, and B. B. Ekanem, “Effects of waste engine oil contamination on the plasticity, strength and permeability of lateritic clay,” International Journal of Scientific & Technology Research, Vol. 25(3): pp 136 – 145, 2014.

[12] F. Ghaffoori, and M. Karpuzcu, “Influence of oil contamination on Geotechnical properties of sandy soil,” International Journal of Advances in Civil and Mechanical Engineering, Vol. 5(5): pp 1 – 4, 2018.

[13] M. Kermani, and T. Ebadi, “The effect of oil contamination on the Geotechnical properties of fine-grained soils,” Journal of Soil and Sediment Contamination, Vol. 21(5) pp 655 – 671, 2012.

[14] J. Joseph and G. Hari, “Investigation on the effect of hydrocarbon spillage on soil properties,” International Journal of Engineering Research and Technology, Vol. 4(10): 136 – 140, 2015.