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ORIGINAL CONTRIBUTION

Effects of Oil Contamination on the Geotechnical Properties of Clayey Soil

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***Abstract*— The leakage of oil products which results in making the soil pollute or impure and alter its physical and mechanical properties due to the presence of hydrocarbons in it. Those hydrocarbons which cannot be passed into soil through the pores and become congest on top of the land. Hence it is necessary to indicate and know the geotechnical properties of the contaminated soil. Recently the modern technique is an encompassing laboratorial system intends to encourage and improve the high level of determining the effects of Oil contaminants on the geotechnical properties of the soil. In this way, the laboratory indications containing the fundamental properties like Atterberg limitations, direct shear, sieve analysis and unconfined compression has been taken from the contaminated soil. The contaminated samples were taken from two different areas of each site containing surface and 1m deep samples which shows the different substantial kinds of variances in the soil consequences after contamination occur in it.**

***Index Terms*— Clayey soil, Oil contamination, Shear strength, Geotechnical properties**

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I. INTRODUCTION

The degradation of the environment resulted from humankind's ruthless exploitation of the earth's resources and the rise of industrialization. Pollution of the earth from petroleum-based substances is considered an enormous explosion of environmental matter because it severely fetters the fundamental standards of soil, water quality, and the weather. Petroleum spills primarily result from oil discovery, mobility, manufacturing, and handling. Diesel fuel product leaks from tankers carrying oil, collisions with vehicles, underground pipeline leaks, and oil pollution from engines all occur frequently in regions near auto repair shops [1]. Oil-based products, such as petrol, alter the physiochemical and microbiological characteristics of the soil and also lower the productivity of tillable and agricultural crops [2]. In addition to contaminating soil, oil spills have disastrous and lethal effects on the community, the financial system, and the geo-environment. The main causes of soil pollution are subterranean container and pipe leaks, the use of fertilizers and chemicals, the infiltration of polluted water from the surface into underlying strata, the dissolution of waste from garbage dumps, and the immediate disposal of commercial trash into the soil [3]. Strength, permeability, Maximum Dry Density (MDD), ideal moisture content, etc. are all decreased as a result of oil pollution [4]. This made it feasible to assess potential changes brought on by waste oil spills in the geo-environment and to determine the acceptability of different building materials in the study location's vicinity [4]. Scientists have suggested a variety of approaches that can be used to clean petroleum-contaminated soil, the two most popular of which are bioremediation and oxidation by chemicals. The effectiveness of the contemporary technique for removing the leftover oil waste from recently coated regions with residual oil is remarkable [5]. He investigated the geotechnical properties of diesel oil-contaminated soil and came to the conclusion that, for 4% diesel contamination, the California Bearing Ratio (CBR) value was greater compared to that of uncontaminated soil; however, for 8% and 12%, it decreased. Additionally, the LL and PL of the affected soil had a trend towards decline, while its unconfined compressive strength demonstrated a trend towards increase [6].

Examination of the physical as well as chemical effects of oil from petroleum contamination in soil demonstrated harm to the soil ecosystem. The laboratory experiment demonstrates that oil pollution has a considerable impact on soil parameters such as moisture content, accessible phosphorus, and Total Organic Carbon (TOC) [7]. Scientists have studied the effects of oil contamination and bioremediation on the geotechnical characteristics of highly plastic clayey soil, and the results indicate that oil-based contamination lowered the soil's particular area of surface and the water's ability to interact with the clay particles, which increased the soil's plastic limit and, as a consequence, decreased the index by about 32.26%. For bioremediated soil, an analogous pattern of behavior was seen. Additionally, oil pollution reduced the soil's cohesiveness, internal friction angle, and shear strength, which may be connected to the lubricant properties of oil and the drop in dielectric constant [8]. Based on his observations, investigators examined the impact of compaction activities on the geotechnical characteristics of waste engine oil-contaminated laterite soil. The liquid limit, plastic limit, and plasticity index of the natural soil were 58%, 50%, and 8%, respectively. When the soil was treated up to 4%, the liquid limit initially increased from 58 to 62%, but there was no initial change in the plastic limit. With higher contents, the plasticity index first rose [9]. They

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collaborated on investigating oil-contaminated soil as a possible material for use in civil engineering construction. Their research indicates that oil contamination should be taken into consideration before any civil science and technology project is built, especially one requiring a shallow foundation, because it will negatively affect the soil's angle of friction and cohesion, which is what determines the soil's ultimate bearing capacity and stress-strain relationship [10]. Geotechnical Properties of Waste Engine Oil-Contaminated Laterites were the subject of experiments, and the findings revealed that the contaminated soils were created by combining dry soil samples with 3%, 6%, 9%, and 12% of waste engine oil according to weight. This overall reduction in ideal moisture content, liquid limits, and permeability was observed. For three of the samples, an increase in shear strength, maximum dry density, and CBR was also noted [11]. Studies on the use of nanoscale hydrated calcium carbonate and zero-valent iron in order to enhance the geotechnical characteristics of gas oil-contaminated clay revealed a decrease in UCS, maximum dry density, optimum moisture content, and internal friction angle and an increase in Liquid Limit (LL), Plastic Limit (PL), and cohesion [12].

The impact of crude oil contamination on pile foundation geotechnical behaviour demonstrates that the range of oil contamination degree in the soil alters the induced internal forces in the piles by proportions increasing to 40, 34, and 20% of the shear forces, normal forces, and bending moments, respectively. But with proportions up to 150% [13], the changes in the soil and pile displacements are more severe. They investigated how gas oil contamination affected the geotechnical characteristics of soils with fine and coarse grains, and their findings suggest that as gas oil contamination increased, clay and silt soils' liquid and plastic limits also increased. On the other hand, the UCS of silt soil is negatively impacted by the rise in petrol oil percentage. The increase of clay particles extends the rate of fabric flocculation, which is a critical element for enhancing the unconfined compression strength in clayey soil, according to a study using field emission scanning electron microscopy [14]. The results of a study on the impact of petrol contamination on the geotechnical characteristics of clayey soil showed that Atterberg limits decreased with increasing petrol contamination in clay samples [15]. According to research on the effects of lead and petrol contamination on the geotechnical characteristics of clayey soils, as the amount of lead in the soil increases, the pH of the soil dramatically decreases and the electrical conductivity of the sample increases. The total quantity of ions present in the soil solutions might be used to find justifications for these changes. The impact of natural gas and petroleum pollution on the geotechnical characteristics of fine and coarse-grained soils has been studied, and the findings show that the study included Atterberg limits, compaction, unconfined compression, and direct shear measurements. As it is demonstrated, the quantity of maximum dry density increases as you increase the lead and petrol values in the specimens [16]. Research results show that as pollution levels rise, the soils' cohesiveness and friction angle both diminish. On the contrary, a decrease in the ideal moisture content and maximum dry density was seen [14].

- To investigate whether the land has been contaminated.
- To investigate the changes in geotechnical properties of clayey soil occurred due to oil contamination.

II. MATERIALS AND METHOD

A. Sample Collection

The silty clayey soil is the most common type of subgrade and bedding soil of coastal region of Tianjin City, China. The soil was taken from the coastline region of Tianjin near dagang oil field area from depth of 0.5m up to 1m to avoid unwanted entry of the debris, trash, or organic soil.

B. Sample Preparation

Firstly the soil was pulverized and dried in the oven at (110 and 105) °C for 24 hours, after that all lumps are then broken up into tiny pieces. The experiment was carried out in the laboratory using an assortment of sieves in a sieve shaker. The soil was utilized to prepare all samples after the shaking phase was over. The mass of soil maintained on each sieve was identified to separate and remove stones from the primary structure of soil mass. Four types of samples were prepared, and placed in thick plastic bags to complete the experimental process without any oil evaporation and moisture absorption by soil particles.

C. Experimental Tests

In order to evaluate the geotechnical properties of Oil-Contaminated Samples (OCS), a series of laboratory tests were performed.

- Sieve Analysis (ASTM D6913M-17)
- Moisture content (ASTM D2216-19)
- Atterberg limits (ASTM D4318-17e1, 2017)
- Specific Gravity (ASTM D854–14)
- Direct Shear (ASTM D3080/D3080M-11, 2011)
- UCS (ASTM D2166/D2166M16, 2016)

III. RESULTS AND DISCUSSION

An inclusive laboratory tests were carried out to determine the Effects of Oil Contamination on geotechnical properties of clayey soil of two different samples of the area i.e., sample 1 and 2.

These tests were based on the following results.

A. Sieve Analysis

The above approach is mostly used to grade aggregates. The findings are utilized to assess if the arrangement of particle sizes complies with the relevant standard criteria and to give the information needed to govern the manufacture of different aggregate products and blends incorporating aggregates. One of the parameters used to determine if the soil is adequate for constructing infrastructure such as dams, embankments, and roads is particle size. Particle size analysis data reveals that the clayey soil particles did not pass as the contamination level rose because of the contaminants from oil.

TABLE I
SIEVE GRAIN ANALYSIS (PARTICLE SIZE DISTRIBUTION) DATA OF SAMPLE 1 (1 METER DEEP)

Sieve No.	Sieve Opening	Cumulative Soil Retained (gram)	Mass Retained (%)	Percent Passing (%)
#4	4.75	38.84	7.788	92.212
#8	2.36	94.39	18.927	73.285
#16	1.18	89.07	17.860	55.424
#20	0.85	34.47	6.912	48.512
#30	0.6	45.37	9.098	39.414
#50	0.3	57.66	11.562	27.852
#80	0.18	52.57	10.541	17.311
#100	0.15	12.07	2.420	14.891
#200	0.075	26.6	5.334	9.557
Pan	47.66	9.557	0.000	
Total	498.7			

TABLE II
COEFFICIENT OF UNIFORMITY (CU) AND COEFFICIENT OF GRADATIONS (CC)

% Gravel	7.79	D60 (mm)	1.482	Cu = D60/D10	19.764
% Sand	82.65	D30 (mm)	0.324	Cc = D30/D60*D10	0.005
% Fine	9.56	D10 (mm)	0.075		

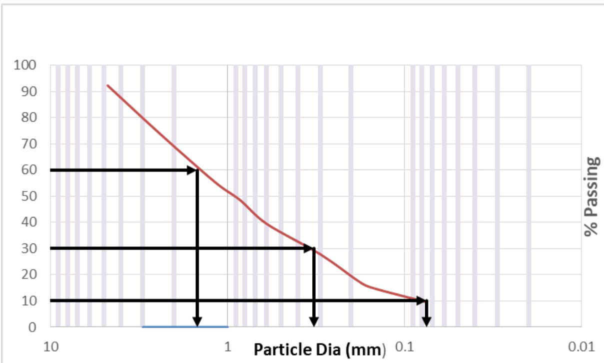

Fig. 1. Sieve Grain Analysis (Particle Size Distribution) data of Sample 1(1 meter Deep)

TABLE III
SIEVE GRAIN ANALYSIS (PARTICLE SIZE DISTRIBUTION) DATA OF SAMPLE 1 (SURFACE)

Sieve No.	Sieve Opening	Cumulative Soil Retained (gram)	Mass Retained (%)	Percent Passing (%)
#4	4.75	37.54	7.552	92.448
#8	2.36	92.41	18.591	73.857
#16	1.18	87.09	17.521	56.336
#20	0.85	33.56	6.752	49.585
#30	0.6	27.17	5.466	44.119
#50	0.3	26.14	5.259	38.860
#80	0.18	49.35	9.928	28.932
#100	0.15	22.46	4.518	24.413
#200	0.075	34.3	6.900	17.513
Pan	87.05	17.513	0	
Total	497.07			

TABLE IV
COEFFICIENT OF UNIFORMITY (CU) AND COEFFICIENT OF GRADATIONS (CC)

% Gravel	7.75	D60 (mm)	1.427	Cu = D60/D10	19.023
% Sand	74.94	D30 (mm)	0.193	Cc = D30/D60*D10	0.002
% Fine	17.51	D10 (mm)	0.075		

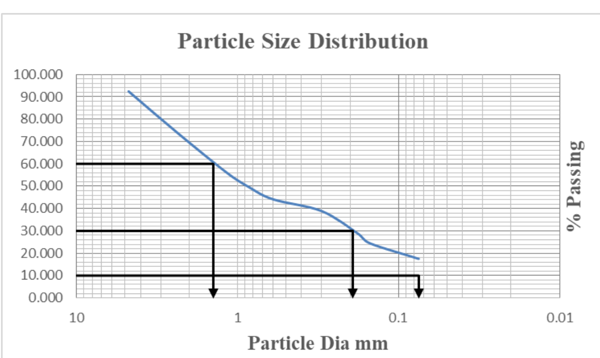

Fig. 2. Sieve Grain Analysis (Particle Size Distribution) data of Sample 1 (Surface)

TABLE V
SIEVE GRAIN ANALYSIS (PARTICLE SIZE DISTRIBUTION) DATA OF SAMPLE 2 (1 METER DEEP)

Sieve No.	Sieve Opening	Cumulative Soil Retained (gram)	Mass Retained (%)	Percent Passing (%)
#4	4.75	39.94	8.051	91.949
#8	2.36	93.4	18.827	73.122
#16	1.18	90.2	18.182	54.941
#20	0.85	32.4	6.531	48.410
#30	0.6	46.5	9.373	39.036
#50	0.3	55.71	11.230	27.807
#80	0.18	51.7	10.421	17.386
#100	0.15	13.86	2.794	14.592
#200	0.075	26.67	5.376	9.216
Pan	45.72	9.216	0.000	
Total	496.1			

TABLE VI
COEFFICIENT OF UNIFORMITY (CU) AND COEFFICIENT OF GRADATIONS (CC)

% Gravel	8.05	D60 (mm)	1.508	Cu = D60/D10	20.111
% Sand	82.73	D30 (mm)	0.325	Cc = D30/D60*D10	0.005
% Fine	9.22	D10 (mm)	0.075		

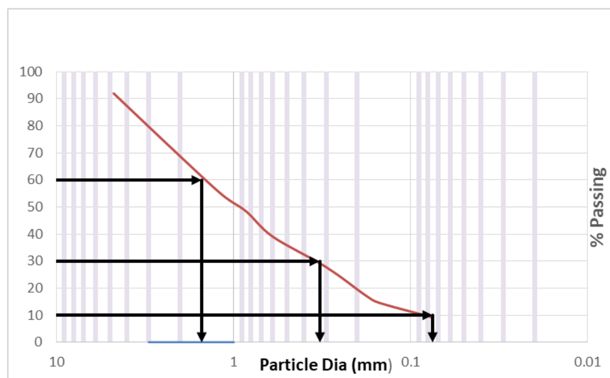

Fig. 3. Sieve Grain Analysis (Particle Size Distribution) data of Sample 2 (1 meter deep)

TABLE VII
SIEVE GRAIN ANALYSIS (PARTICLE SIZE DISTRIBUTION) DATA OF SAMPLE 2 (SURFACE)

Sieve No.	Sieve Opening	Cumulative Soil Retained (gram)	Mass Retained (%)	Percent Passing (%)
#4	4.75	42.61	8.543	91.457
#8	2.36	89.67	17.979	73.478
#16	1.18	86.88	17.419	56.059
#20	0.85	28.9	5.794	50.265
#30	0.6	43.7	8.762	41.503
#50	0.3	51.9	10.406	31.097
#80	0.18	48.2	9.664	21.433
#100	0.15	18.46	3.701	17.732
#200	0.075	29.57	5.929	11.803
Pan	58.87	11.803	0	
Total	498.76			

TABLE VIII
COEFFICIENT OF UNIFORMITY (CU) AND COEFFICIENT OF GRADATIONS (CC)

% Gravel	8.54	D60 (mm)	1.447	Cu = D60/D10	19.293
% Sand	79.66	D30 (mm)	0.286	Cc = D30/D60*D10	0.004
% Fine	11.8	D10 (mm)	0.075		

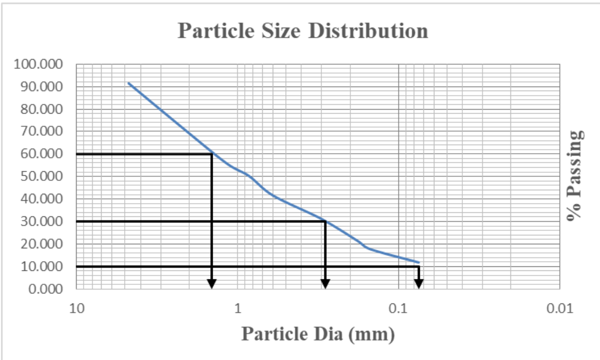

Fig. 4. Sieve Grain Analysis (Particle Size Distribution) data of Sample 2 (Surface)

B. Liquid Limit

Following are the results of the liquid limit test.

TABLE IX
LIQUID LIMIT OF SAMPLE 2 (SURFACE)

S. No.	Trials	Blows	Moisture Content (%)	Liquid Limit (LL)
1	1	16	28.6	
2	2	24	27.66	28.5
3	3	29	29.46	

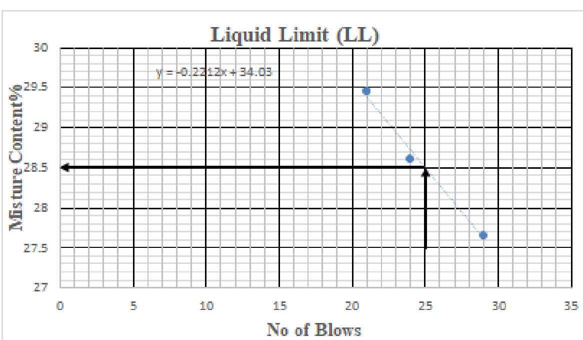

Fig. 5. Liquid Limit of Sample 2 (Surface)

TABLE X
LIQUID LIMIT OF SAMPLE 2 (1METER DEEP)

S. No.	Trials	Blows	Moisture Content (%)	Liquid Limit (LL)
1	1	26	27.20	
2	2	24	29.48	28.17
3	3	21	29.68	

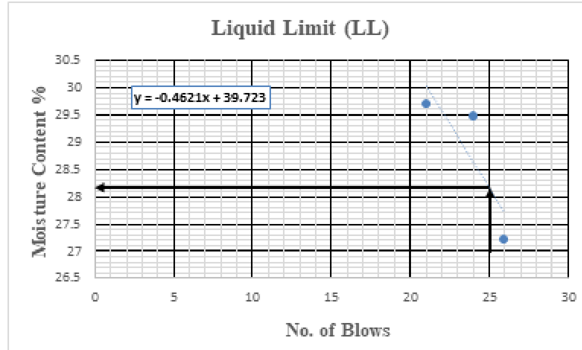

Fig. 6. Liquid Limit of Sample 2 (1meter deep)

TABLE XI
LIQUID LIMIT OF SAMPLE 1 (SURFACE)

S. No.	Trials	Blows	Moisture Content (%)	Liquid Limit (LL)
1	1	26	31.34	
2	2	24	33.44	32.313
3	3	19	35.70	

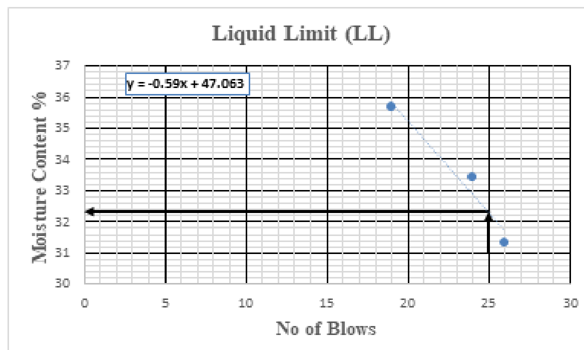

Fig. 7. Liquid Limit of Sample 1 (Surface)

TABLE XII
LIQUID LIMIT OF SAMPLE 1 (1METER DEEP)

S. No.	Trials	Blows	Moisture Content (%)	Liquid Limit (LL)
1	1	18	29.10	
2	2	24	24.25	24.305
3	3	26	24.18	

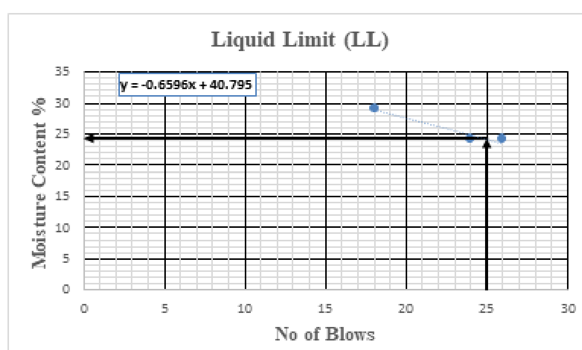

Fig. 8. Liquid Limit of Sample 1 (1meter deep)

C. Plastic Limit

Following are the results of the plastic limits

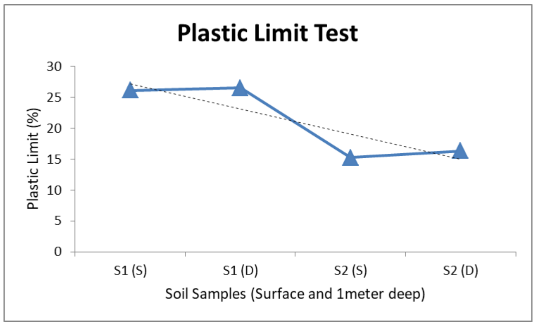

Fig. 9. Plastic Limit of all samples

Plasticity index (PI) of the samples is 3.81.

D. Moisture Content

The oil reduces the MDD and OMC because of dissipation of the compaction hammer energy by oil which decreases the water absorption.

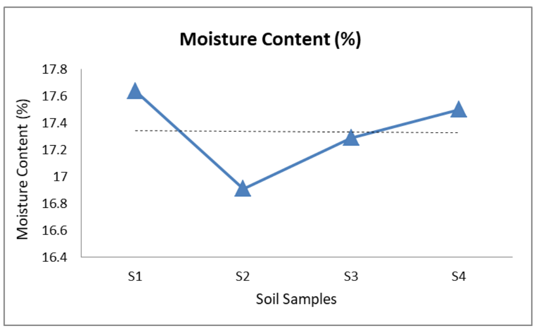

Fig. 10. Moisture Content of all samples

E. Specific Gravity

Following is the graphical representations of the results of the specific gravities of different soil samples.

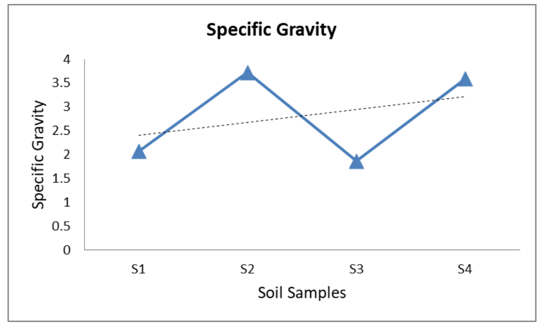

Fig. 11. Specific gravity of different soil samples

F. Unconfined Compression Test (UCS)

Oil lowers cohesiveness by clogging soil pores and spaces amongst soil grains. Moreover, as a pore and integrate-particle fluid, oil is unable to exhibit attachment and sticky properties. Due to the non-polar nature of oil, its atoms cannot form bonds with charged surfaces of minerals made of clay or water. It will result in an indistinguishable stage that works as a grease in the soil-water interaction and reduces the cohesiveness and UCS of contaminated soil. Additionally, when the oil concentration rises, the failure strain continuously decreases. The oil pollution causes an abrupt spike in the unconfined compressive strength, followed by a significant decline, which was observed when the durability increased.

TABLE XIII
UNCONFINED COMPRESSION TEST OF SAMPLE 1 (SURFACE)

Deformation Dial Gauge Readings	Proving Ring Reading	Strain	Load P	1-strain	Effective Area (mm2)	Compressive Stress
0	0	0	0	0	237.82	0
10	0.1	0.0013	7.5	0.998666	238.132	0.0314951
20	0.2	0.0027	15	0.997333	238.44	0.0629089
30	0.3	0.003	22.5	0.997	238.76	0.0942368
40	0.4	0.0053	30	0.994666	239.075	0.1254836

TABLE XIV
UNCONFINED COMPRESSION TEST OF SAMPLE 1 (1METER DEEP)

Deformation Dial Gauge Readings	Proving Ring Reading	Strain	Load P	1-strain	Effective Area (mm2)	Compressive Stress
0	0	0	0	0	234.94	0
10	0.1	0.0013	7.5	0.998666	235.248	0.031881
20	0.2	0.0027	15	0.997333	235.557	0.063678

TABLE XV
UNCONFINED COMPRESSION TEST OF SAMPLE 2 (SURFACE)

Deformation Dial Gauge Readings	Proving Ring Reading	Strain	Load P	1-strain	Effective Area (mm2)	Compressive Stress
0	0	0	0	0	248.87	0
10	0.1	0.0013	7.5	0.998666667	249.19	0.030097516

TABLE XVI
UNCONFINED COMPRESSION TEST OF SAMPLE 2 (1METER DEEP)

Deformation Dial Gauge Readings	Proving Ring Reading	Strain	Load P	1-strain	Effective Area (mm2)	Compressive Stress
0	0	0	0	0	235.09	0
10	0.1	0.0013	7.5	0.998666	235.4	0.031860
20	0.2	0.0027	15	0.997333	235.7	0.063640

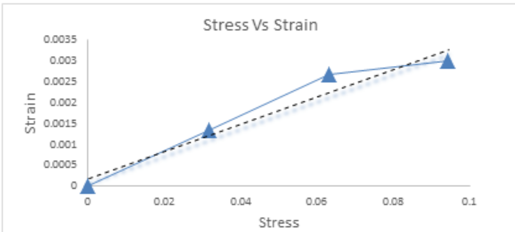

Fig. 12. Unconfined Compression Test of Sample 1 (Surface)

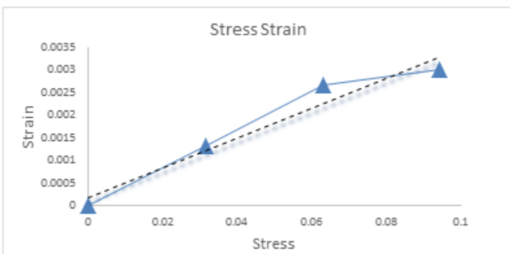

Fig. 13. Unconfined Compression Test of Sample 1 (1meter deep)

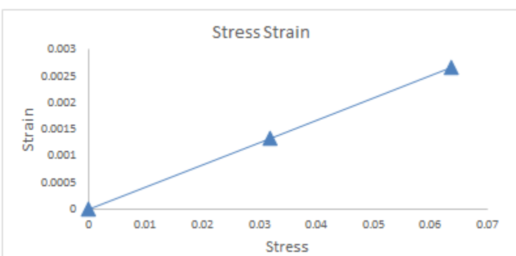

Fig. 14. Unconfined Compression Test of Sample 2 (Surface)

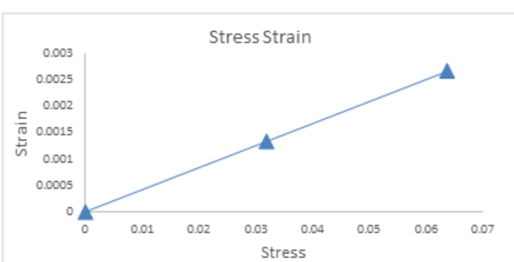

Fig. 15. Unconfined Compression Test of Sample 2 (1meter deep)

Fig. 16. Failure pattern of soil sample 1 (surface and 1meter deep) of the unconfined compression test (UCS)

Fig. 17. Failure pattern of soil sample 2 (surface and 1meter deep) of the unconfined compression test (UCS)

G. Direct Shear

Direct shear experiments were conducted to ascertain the resistance to shear of the specimens. The stress-displacement diagram swings lower with increasing amount of oil in the petroleum-contaminated soil specimens, and the ground strength decreases. This experiment demonstrates how oil has an analogous function to water in that it enhances the likelihood of connect-particle slippage, which lowers the shear strength of polluted soils.

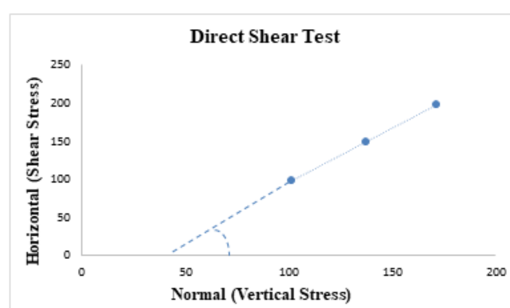

Fig. 18. Direct Shear Test of Sample 1 (1meter deep)

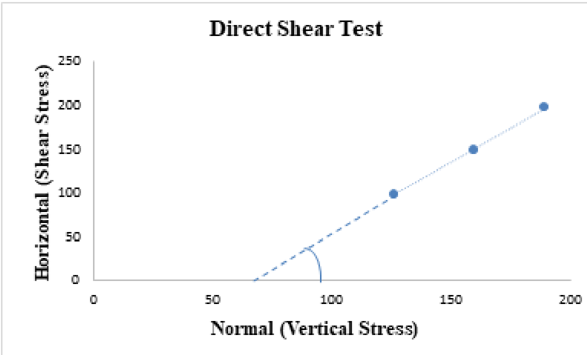

Fig. 19. Direct Shear Test of Sample 2 (1meter deep)

IV. CONCLUSION

Following are the outcome points of the investigation.

- Oil contamination reduces the soil's ability to shear, cohesiveness, and frictional angle, allowing oil to have a lubrication action and causes the value of the dielectric constant to drop.
- Typically, oil contamination reduces the permeability and durability of the soil specimens.
- Under some uncommon circumstances, oil pollution and biological remediation leads to reduced soil expanding, swelling pressure, and increasing soil settling. Although the impact of oil contamination on shear strength metrics varies depending on what sort of soil, it always results in a reduction in maximum shear strength.
- The effects of oil pollution over a long period of time (ageing) on the geotechnical characteristics of soil and its behavior ought to be assessed in relation to the findings of the current experiments. As a result, the issue of connection between the functional groups found in the soil solids and the contaminated oil must be taken into account in further studies.

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